Highly nonlinear Ablative Rayleigh-Taylor Instability on NIF

Presentation to

NIF User Group Meeting

February 13th, 2012

Alexis Casner and Abl RT team

CEA, DAM, DIF, F-91297 Arpajon , FRANCE

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Ablative Rayleigh-Taylor Instability (Abl RT) Collaboration

- PI name and institution: A. Casner (CEA DAM DIF, France)
- CEA Collaborators
- L. Masse (ablative RTI), O. Poujade (RTI turbulence), D. Galmiche,

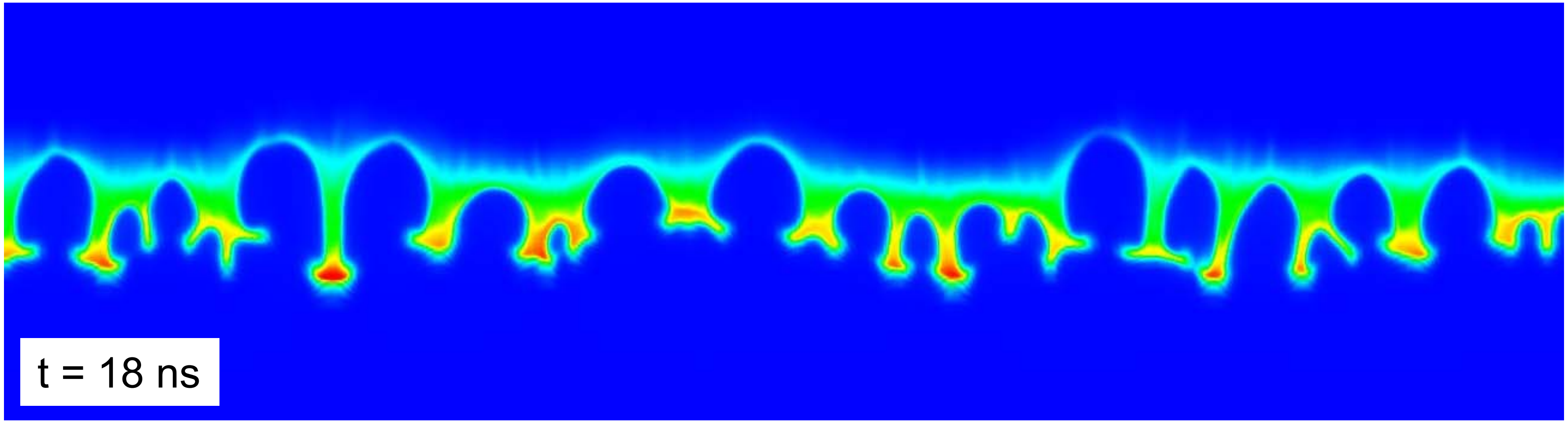
S. Liberatore (hohlraum designers), B. Delorme (PhD student)
- P. Loiseau (LPI), F. Girard, L. Jacquet (backlighters), L. Videau (shrapnel)

- LLNL Collaborators
- V. Smalyuk (co-PI), H.S. Park, D. Martinez, D. Bradley, B. Remington
- J. Kane (Eagle nebula proposal designer)
- AWE Collaborator: A. Moore (RadT platform expert)

- I. Igumenshev in charge of Direct Drive design (Laboratory of Laser Energetics, Rochester)
- Prof. P. Clavin (Institut de Recherche Phénomènes Hors équilibre, Aix-Marseille University)
- M. Olazabal-Loumé (CELIA, University of Bordeaux)
- S. Abarzhi (U. Chicago)
- Prof. S. Sarkar (Department of Mechanical and Aerospace Enginneering, UCSD)

Ablative RT proposal objectives

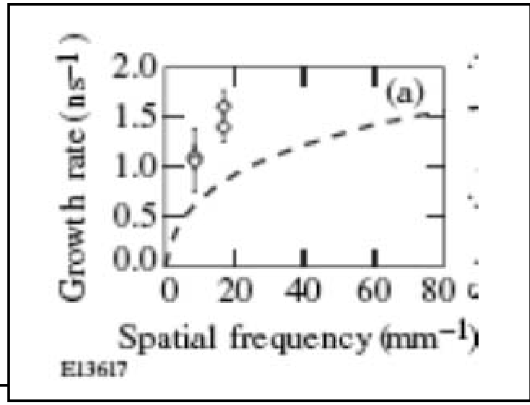
- The effect of ablation on RTI growth rate depends on the irradiating scheme: direct versus indirect drive.
- Multimode ablative Rayleigh Taylor Instability is not well understood, as well as turbulent front hydrodynamics.

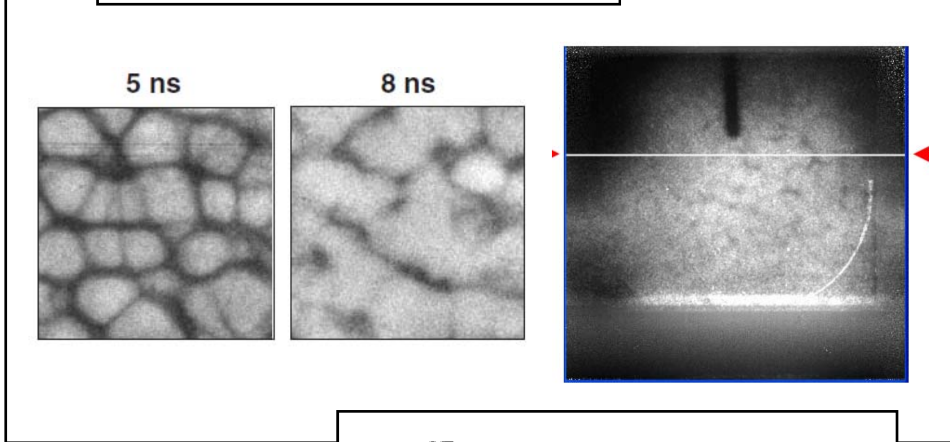


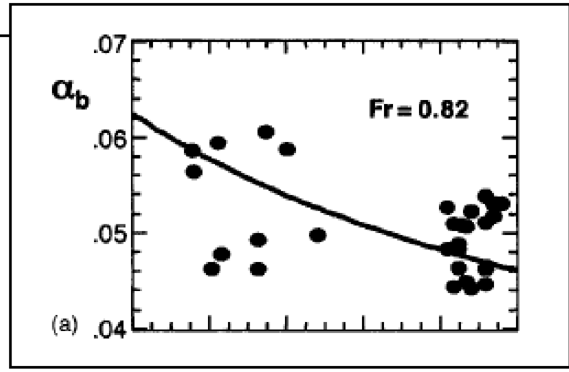
- NIF will accelerate targets over much larger distances (x6) and over longer time periods than ever achieved.
- In one shot, growth of RT modulations can be measured from the weakly nonlinear stage near nonlinear saturation levels to the highly nonlinear bubble-competition, bubble-merger regimes and perhaps into a turbulent-like regime.
- The result of the first DD planar RT shot on NIF will lead the way for academic IFE studies (Polar Direct Drive, Shock Ignition).
- We can perform these experiments right now, without any new diagnostics.
- We are developping a gas-filled hydrodynamics platform usefull for future experiments (Eagle nebula, ….)

ARTI Proposal goals: Study ablative Rayleigh-Taylor in deeply non-linear regime

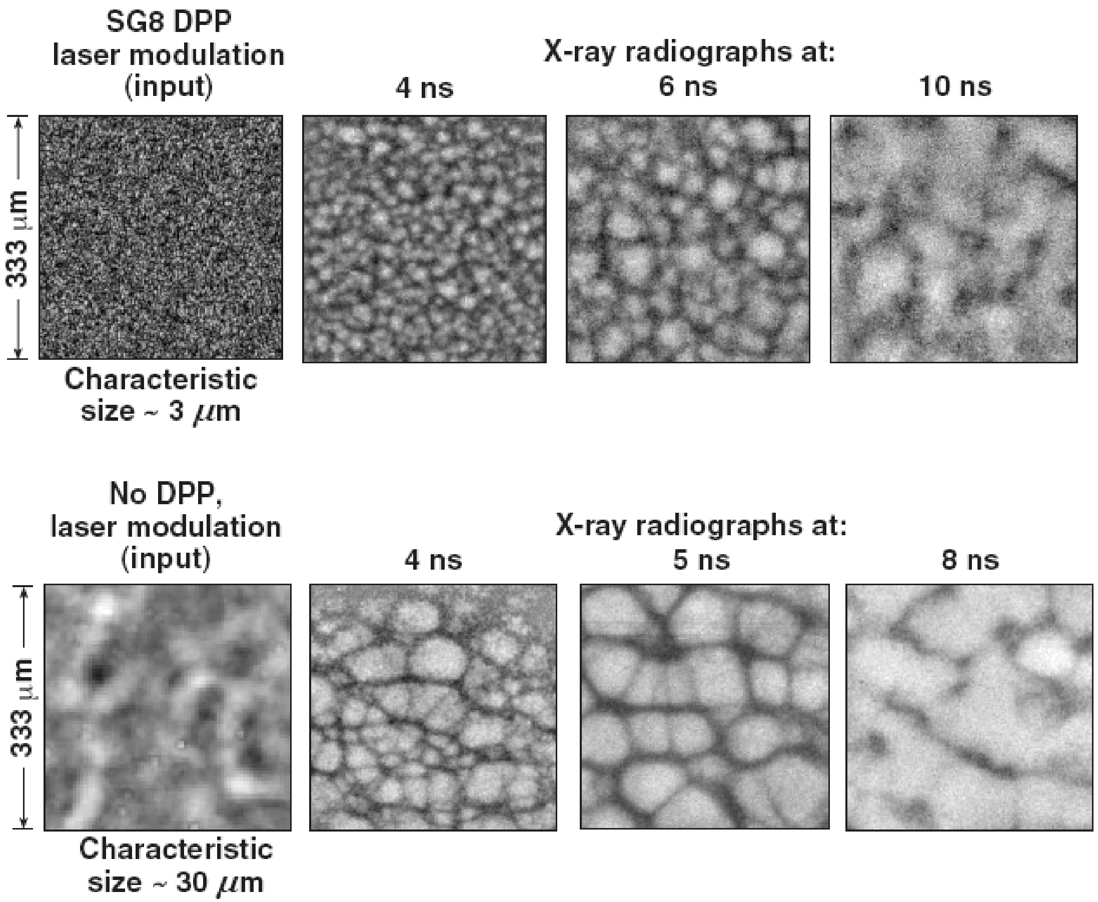
- Non-linear mode coupling
- Ablative destabilization
- Bubble-competition and merger
- Transition to turbulence and influence of initial conditions
- Address effect of ablation on terminal bubble velocity



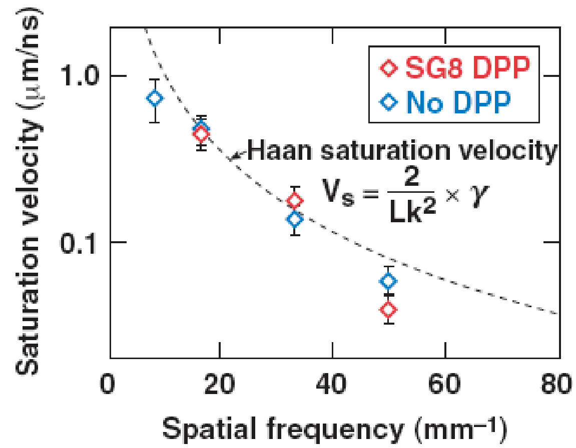




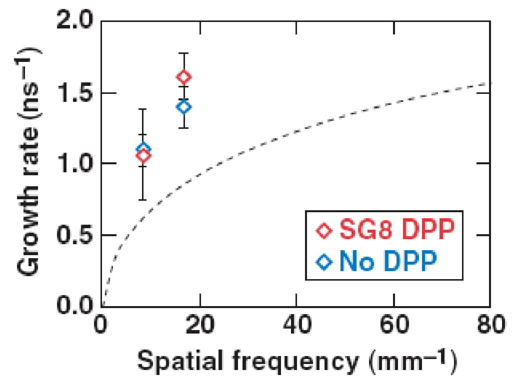
Broadband modulations become larger as they grow nonlinearly



- 50-µm thick CH foils were driven with 12-ns-square laser pulses at 5×10^{13} W/cm^2



- Betti–Goncharov growth rate $\gamma = 0.94\sqrt{\frac{kg}{1 + kL_m}} - 1.5\, V_a\, k$

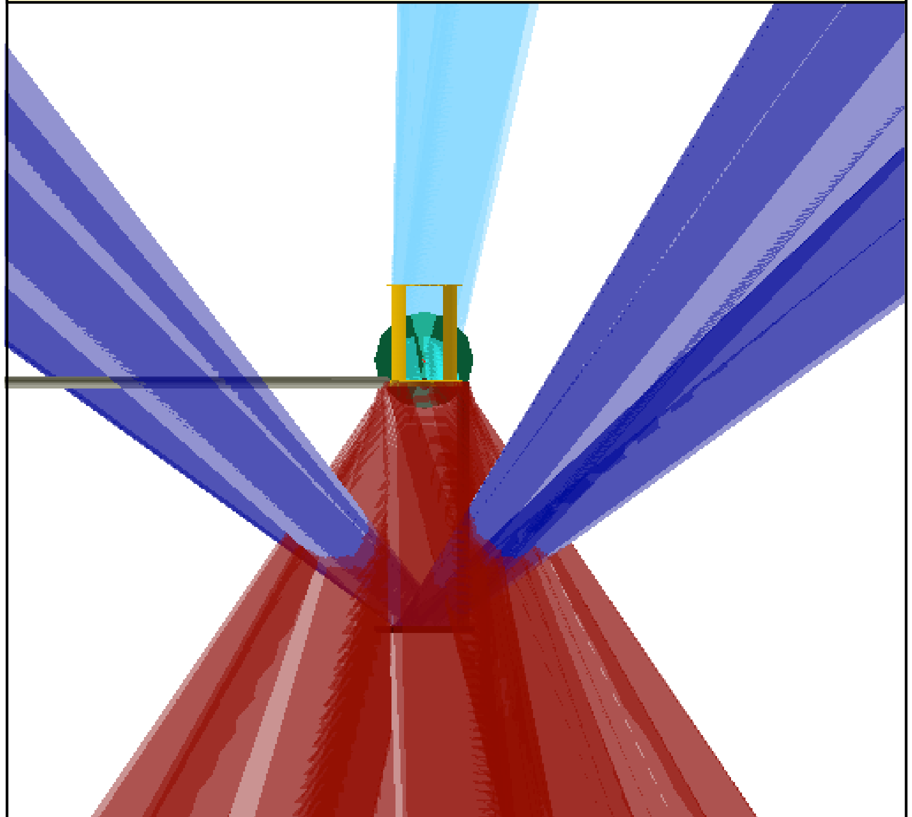


V. A. Smalyuk *et al.*, Phys. Rev. Lett. 95, 215001 (2005).

V. A. Smalyuk *et al.*, Phys. Plasmas. 13, 056312 (2006).

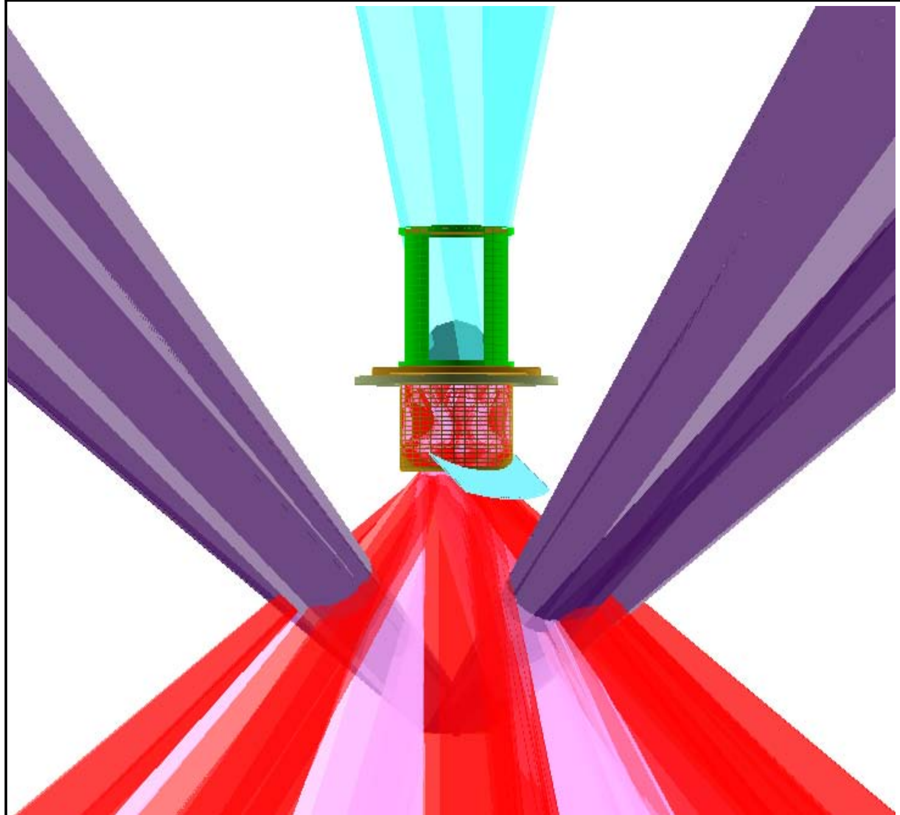
Ablative RT: Two platforms isolate ablative stabilization effects

Direct Drive:
Weak Ablative Stabilization



Laser power – 9.2 TW (5.7 kJ/beam for 20ns) => I~4.5e14 W/cm^2
8 quads with total energy of 184 kJ for 20 ns

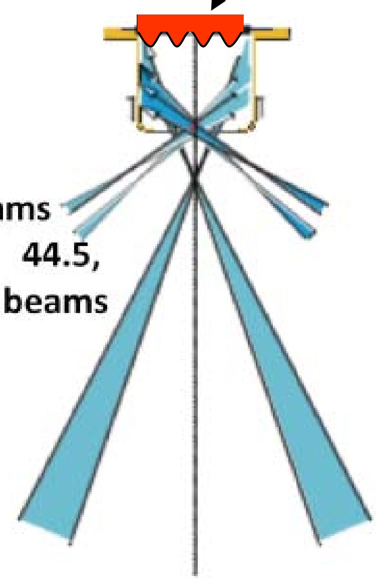
Indirect Drive:
Strong Ablative Stabilization

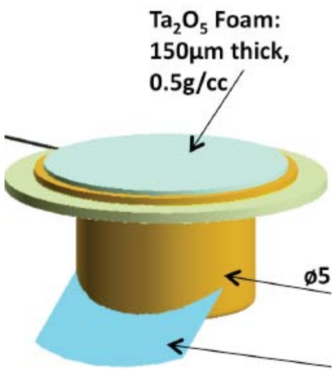


Laser E: 300 kJ
80 beams at 4 kJ/ beam
Tr: ~150 eV over 20 ns

Indirect Drive Abl RT platform is similar to Radiation Transport platform

Physics package instead of Ta_2O_5 foam



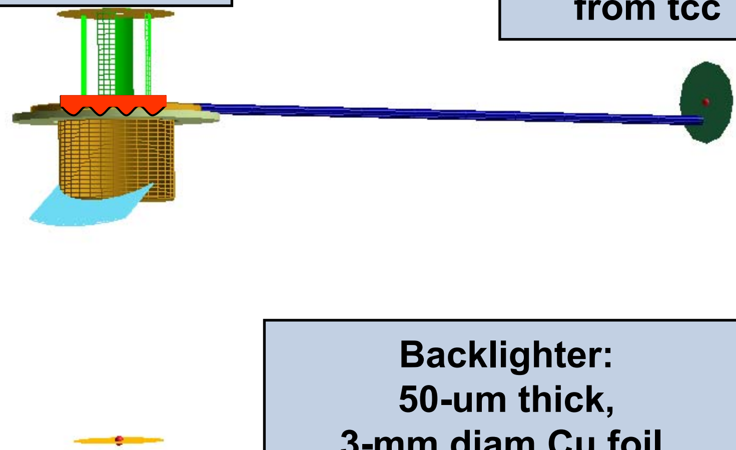


Radiation Transport Burnthrough Target

Indirect Drive Target : Type C

Driven hohlraum: Gas-filled Radtrans hohlraum + CHI foil, at tcc

Side-lighter: 25-um thick, 3-mm diam Sc foil, 1.5 cm from tcc

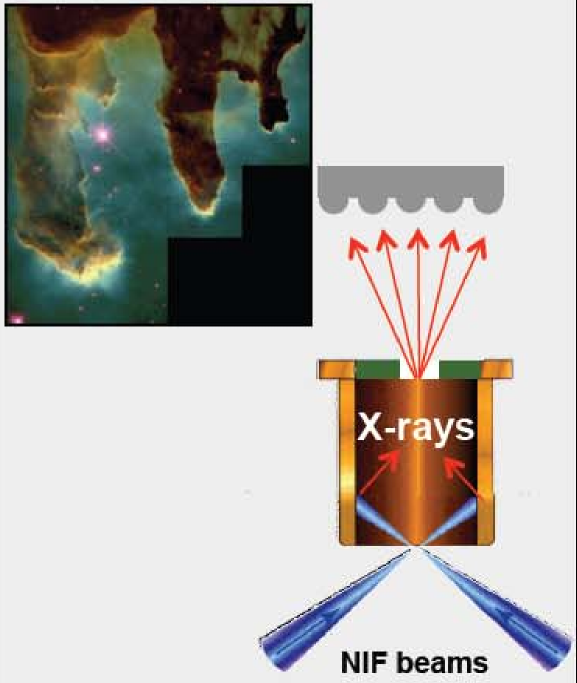


Backlighter: 50-um thick, 3-mm diam Cu foil, 1.5 cm from tcc

Indirect Drive Abl RT Targets are similar to Radiation Transport Targets

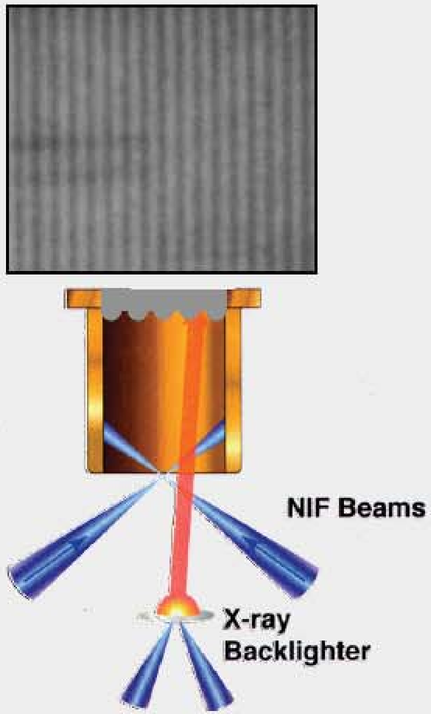
This planar rad-hydro platform can be applied across a wide variety of science experiments

Formation of the Eagle Nebula Pillars



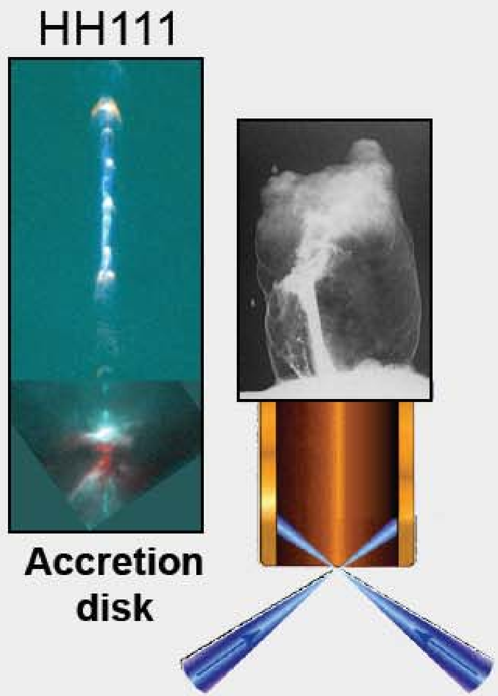
PI: A. Cooper, LLNL

Non-linear ablation front hydrodynamics



PI: A. Casner, CEA

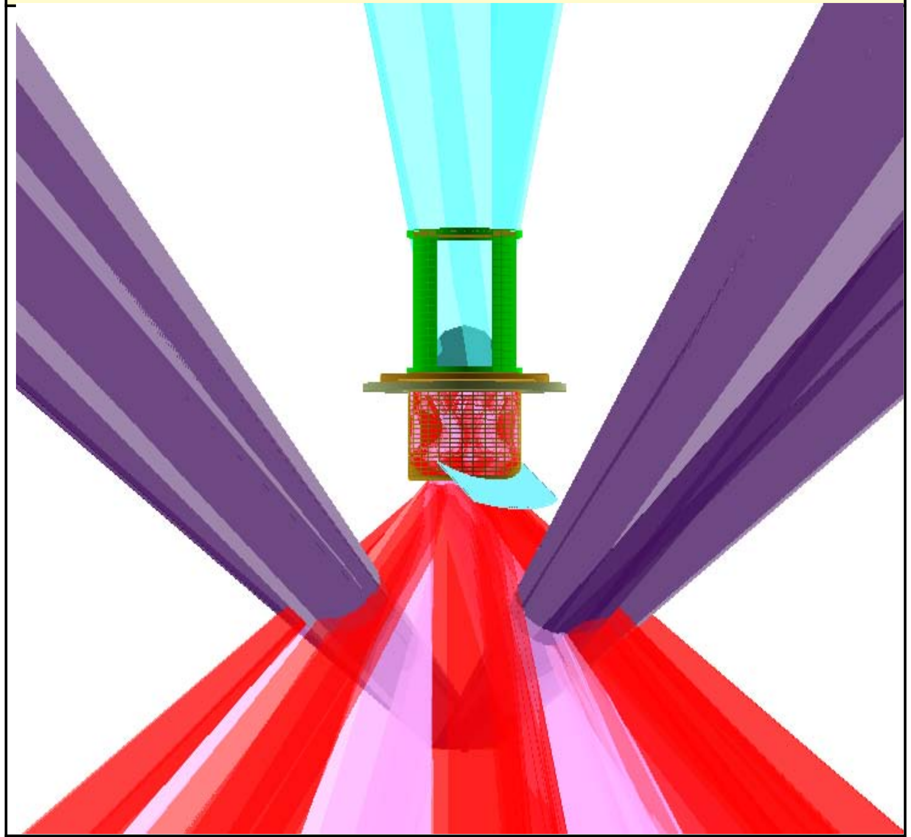
Formation of Herbig-Haro jets



These experiments can utilize a modified planar-radiation hydrodynamics platform

Ablative RT platform: compatible with 5 NIF current experimental configurations (see W. Hsing talk)

Indirect Drive Configuration

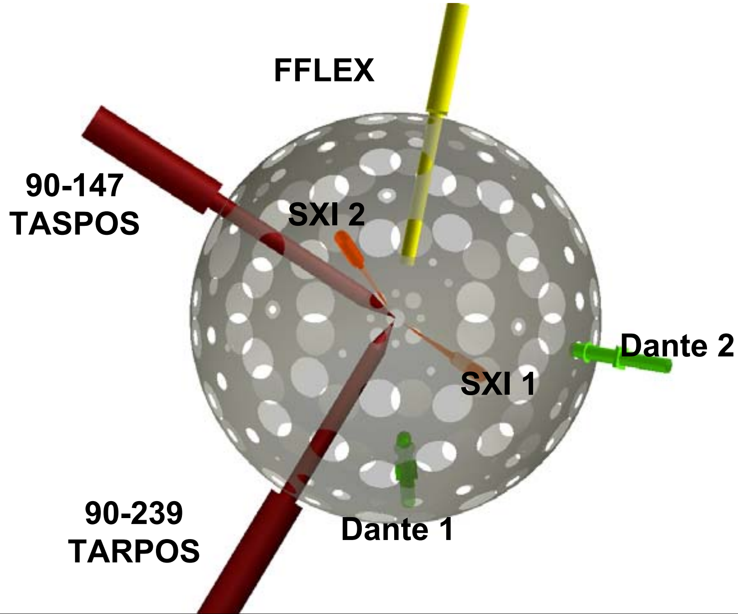


View from 90-78

Drive Pulse
20-ns long, shaped

Total energy 256 kJ

Experimental layout,
Target chamber top view



Diag	Location	Priority	Type	Calib
GXD-1	0-0	1	2	Pre-Shot
DISC-1	90,78	1	3	Pre-Shot
Dante 1	143,274	1	3	Pre-Shot
SXI, T/B	Fixed	3,2	3	Pre-Shot
FABS.NBI/FFLEX	Fixed	2-3	3	Pre-shot
GXD-2	90-315	2	2	Pre-Shot

Indirect Drive Laser Requirements

Laser Parameter	Drive Value	Face-on BL Value	Sidelighter Value	Tolerance
1) Energy range per beam	4 kJ	5 kJ	5 kJ	5%
2) Pulse length	20 ns	10 ns	10 ns	±100 ps
3) Pulse shape	Shaped	10-ns square	10-ns square	Will further define variation on BL pulse
4) Power Balance	nominal	nominal	nominal	
5) SSD bandwidth	90 GHz	0-90 GHz	0-90 GHz	anything is acceptable
6) CPP design	Nominal CPPs	Nominal CPPs	Nominal CPPs	
7) Pulse delays	0.0 ns	6-10 ns	6-10 ns	±65 ps RMS
8) 2-color wavelength offset	No offset	No offset	No offset	
9) Beam pointing jitter	100 µm RMS	100 µm RMS	100 µm RMS	
10) Beam focus	Best focus	Best focus	Best focus	Spot size ± 0.05 mm
11) Post Pulse E upper limit				
12) Beam pointing location	TCC	x=0, y=0,z=-1.5cm	x=-1.06 cm, y=1.06 cm z=0.4337 cm	± 100 µm RMS

NIF Laser Power

Drive Pulse
Shaped pulse
0.5 TW per beam
16 quads
(Q41B, Q46B, Q36B, Q34B, Q26B, Q23B, Q13B, Q11B, Q43B, Q45B,Q35B,Q32B, Q25B,Q22B,Q14B,Q12B)

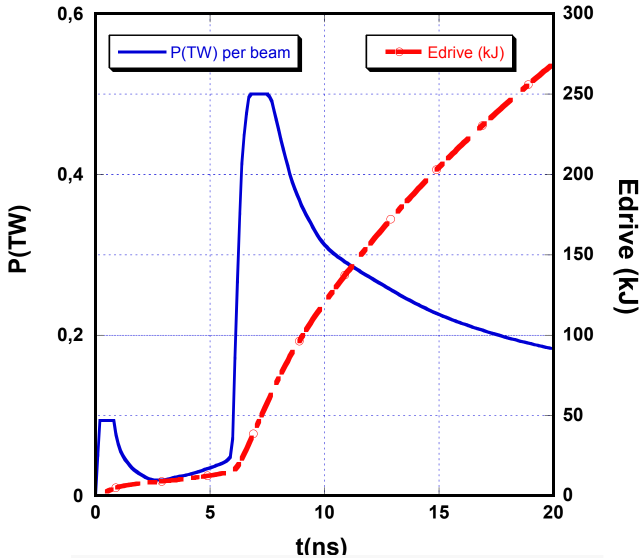
Total energy 256 kJ

Backlighter Pulse
10-ns square
0.5 TW per beam
4 quads for backlighter
(Q11T, Q21T, Q31T, Q34T)
Total energy 80 kJ
Intensity up to 8e14 W/cm^2

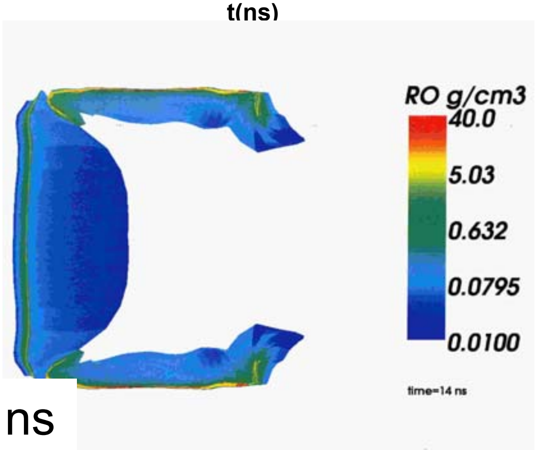
2 quads for side-lighter
(Q16T Q34T)
Total energy 40 kJ
Intensity 4.8e14 W/cm^2

Pulse shape, drive and acceleration

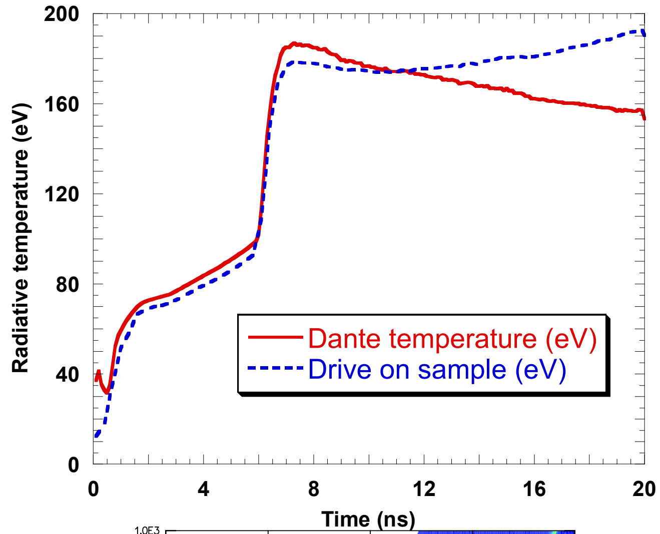
ARTI Radtrans

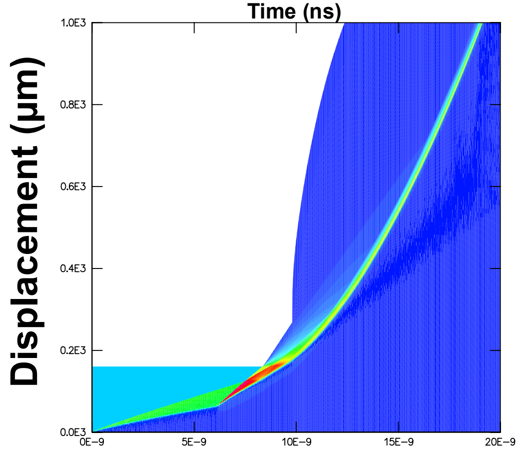


Face on
FOV



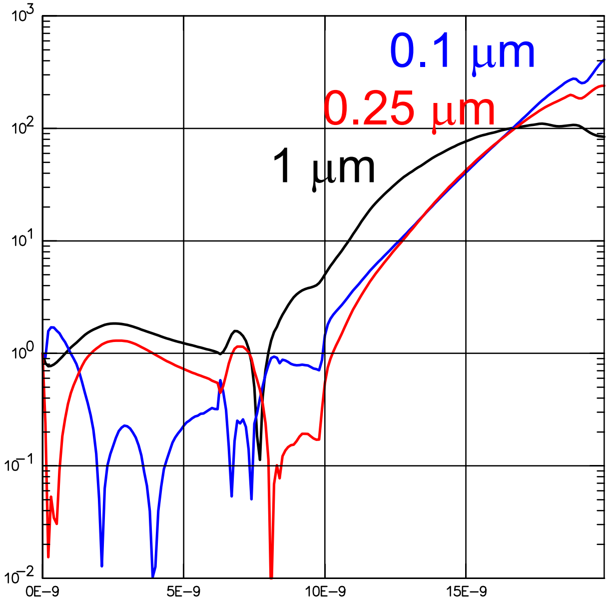
FCI2 CEA Hydrocode

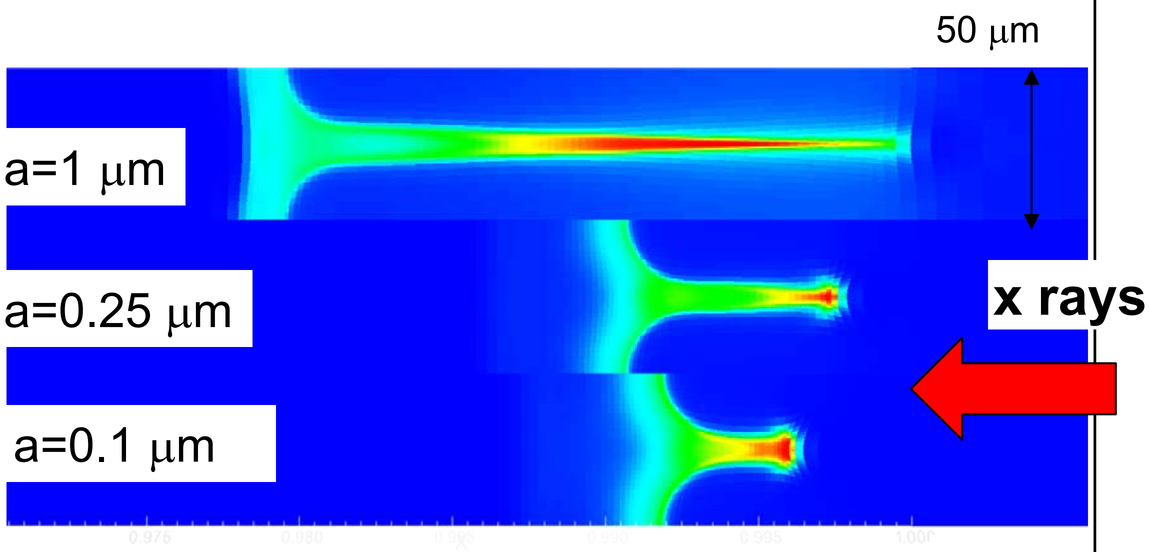




Targets are accelerated over 6x larger distance than on OMEGA

Ablative RT initial measurements use 2D single mode growth to establish ablation velocity, acceleration





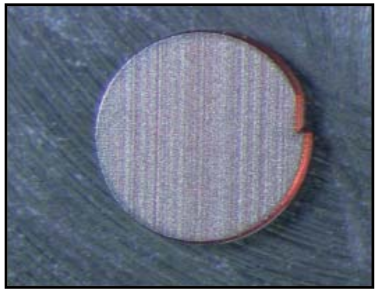
a) Predicted growth factors as a function of time for a single mode λ = 50 µm wavelength perturbation in a 160 µm thick doped foil for three different initial p-t-v amplitudes, 0.1, 0.25 and 1 µm.

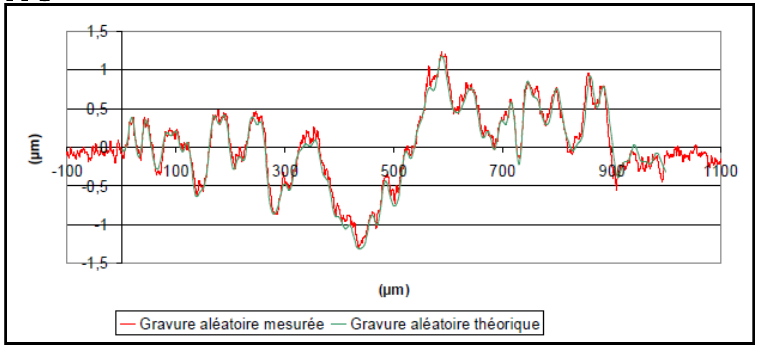
b) Corresponding side-on images of RT spikes at 20 ns.

Extend measurements on indirect platform to multimode perturbations

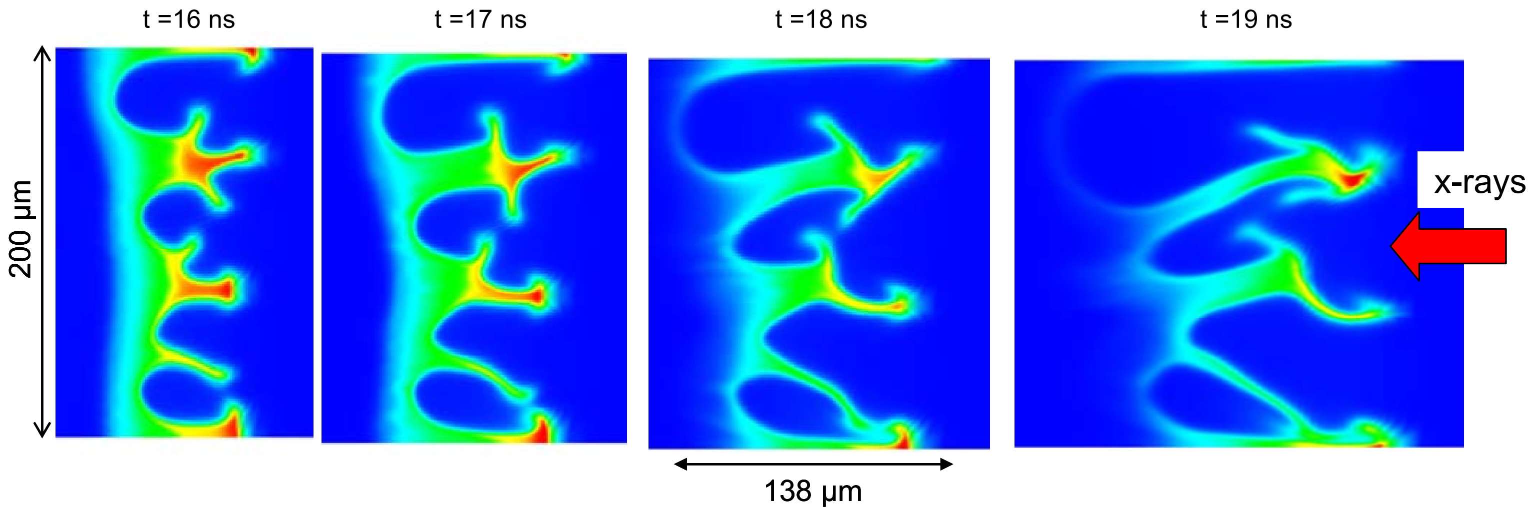
Probe weakly nonlinear stage near nonlinear saturation levels to the highly nonlinear bubble-competition, bubble-merger regimes, turbulent-like regime

20 μm< λ < 1000 μm white noise with σ_{rms}=1 μm



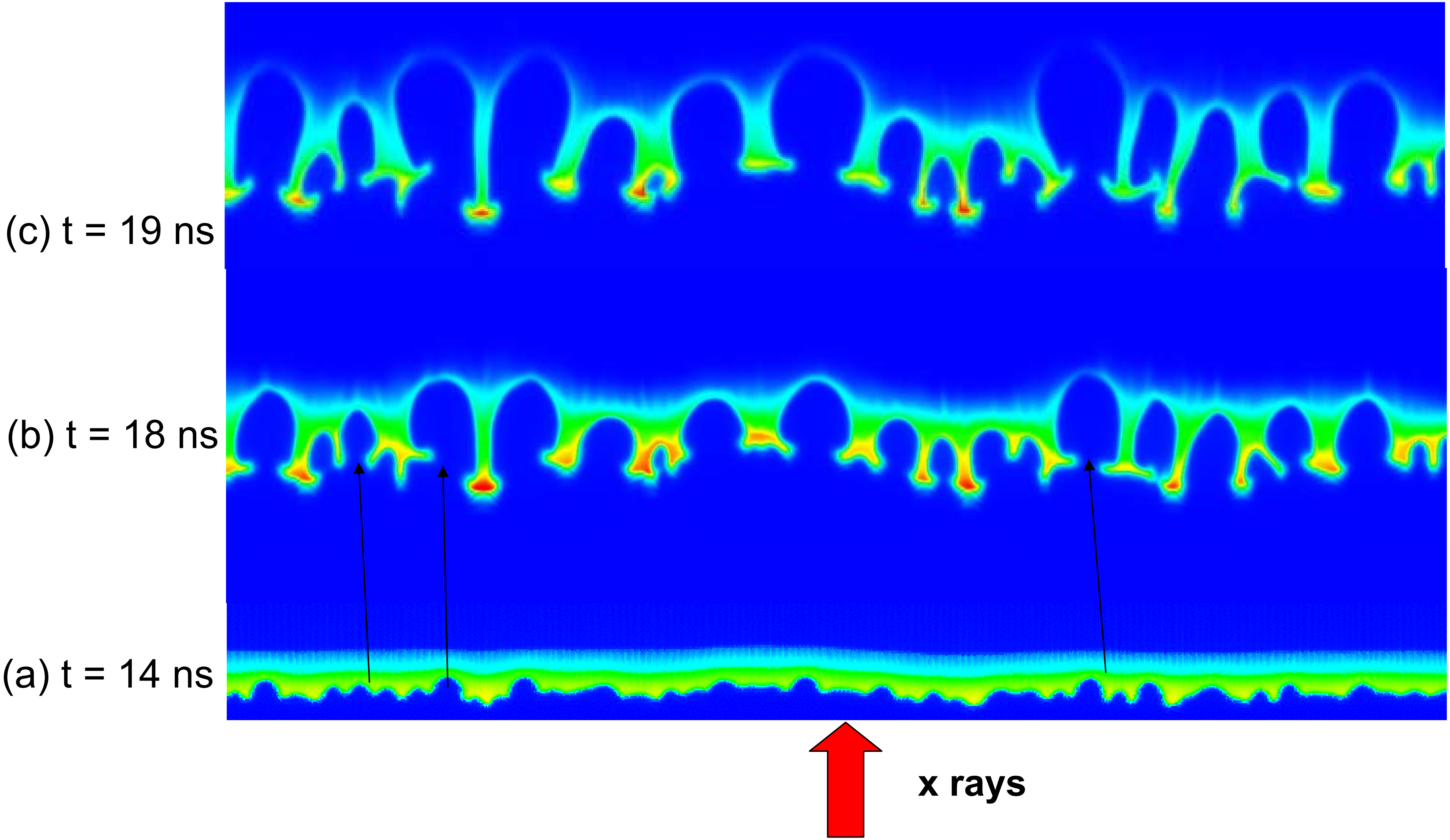


Physics packages could been made (CEA target lab)



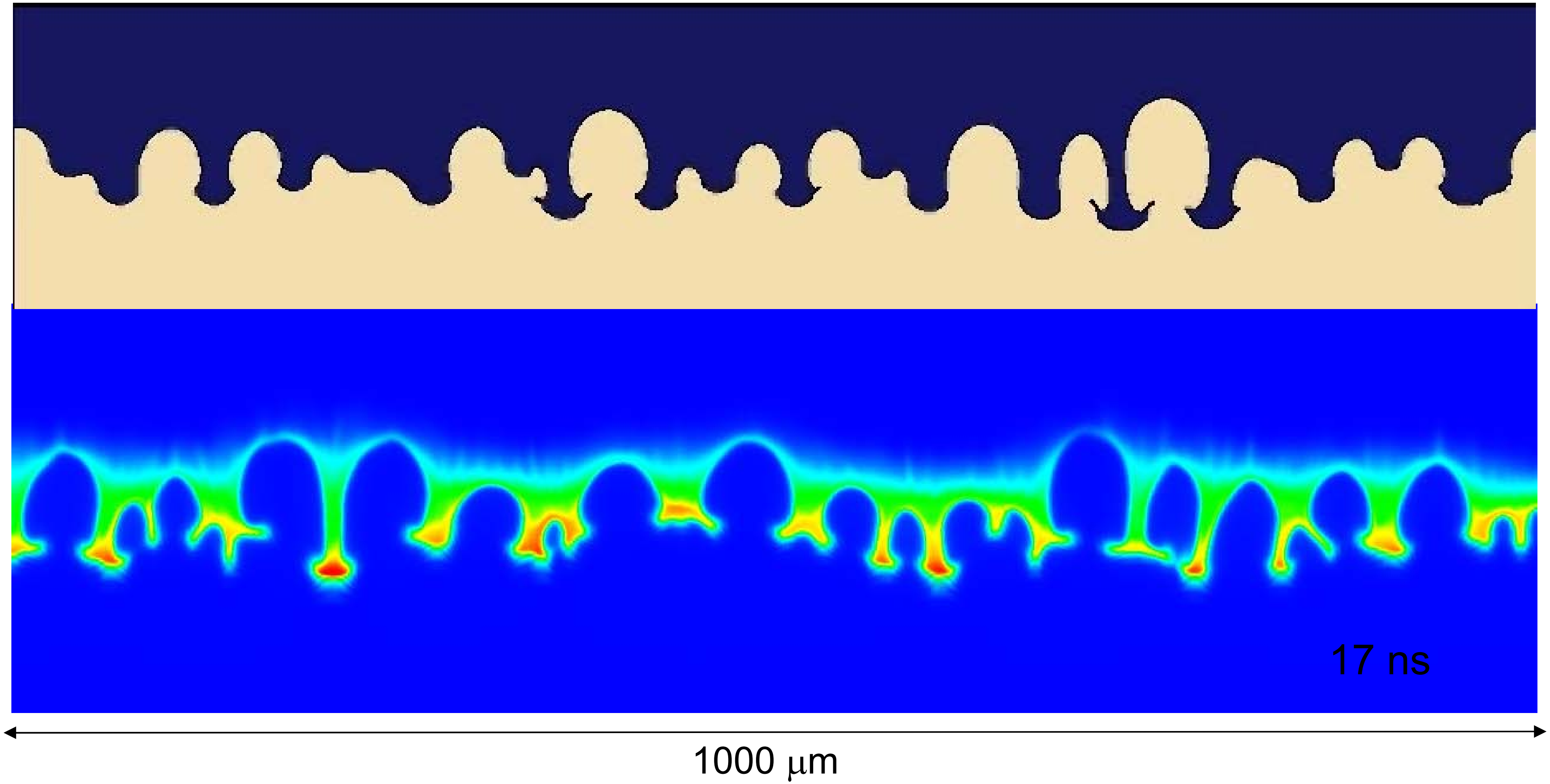
Side-on, post-processed images illustrating the bubble-merger regime reached in ID experiments with initial 2D multimode perturbations with initial rms amplitude of 1 µm.

At least one bubble generation in ID from 14 to 18 ns



Theoretical model catch physics

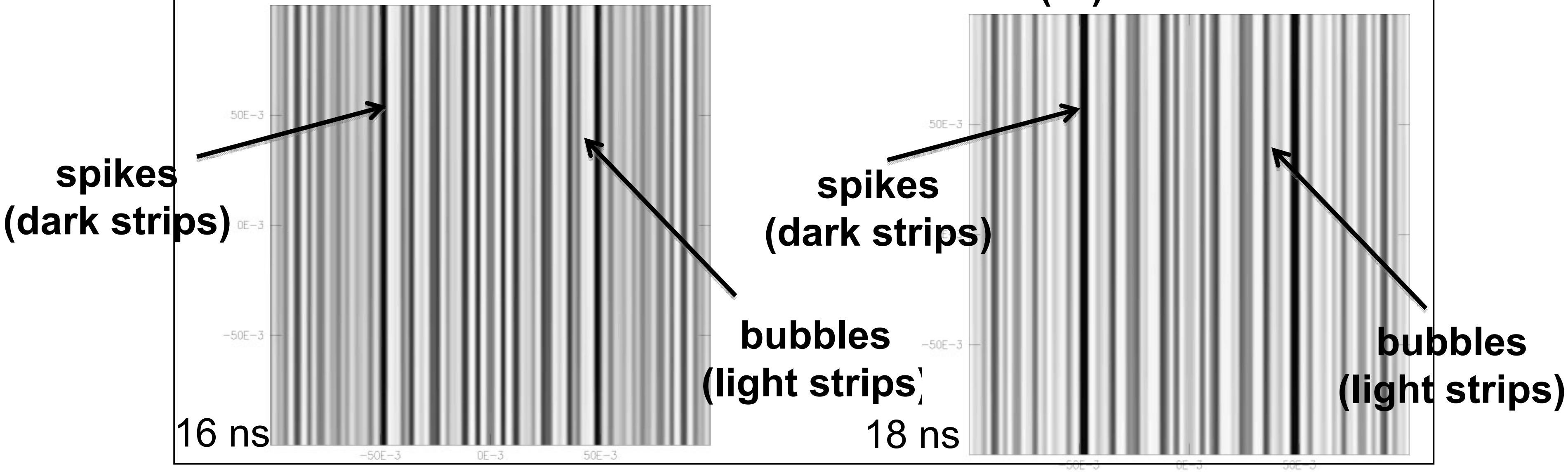
Model, boundaries integral method



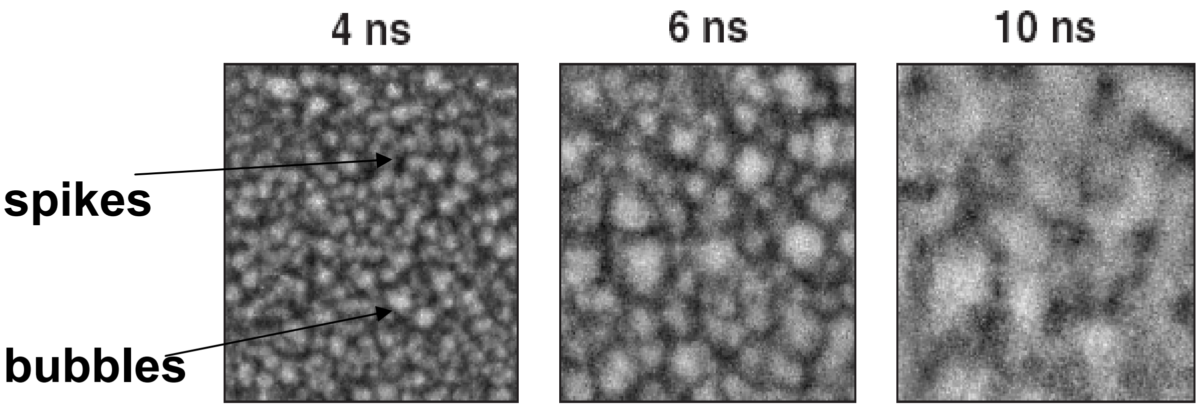
2D FCI2 simulations multimode pattern

Comparison of ID and DD X-ray radiography (Face –on postprocessed images)

2 D multimode broadband (ID)

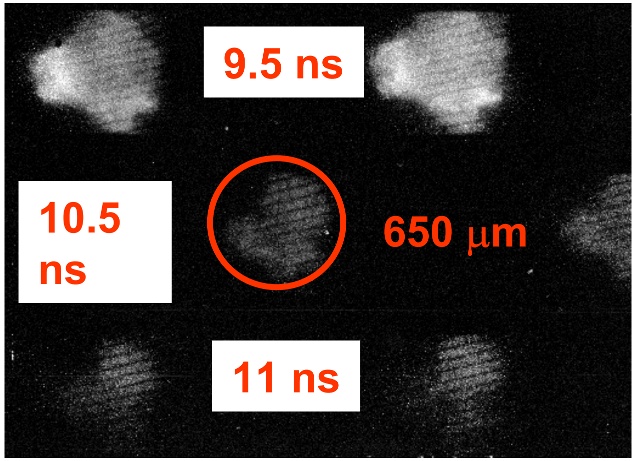


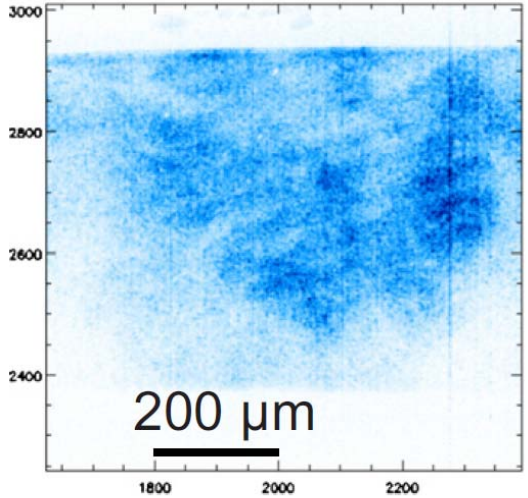
3 D multimode broadband (DD)



Hohlraum closure has to be MEASURED

Bradley, PoP 2007



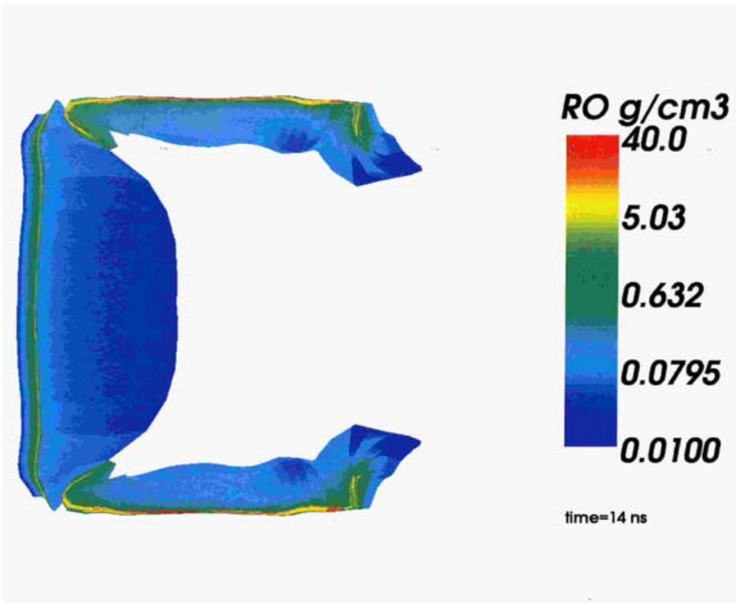


Masse, Huser, Casner

Phys. Plasmas. 18, 012706 (2011).
Phys. Rev. E 83, 055401(R) (2011).

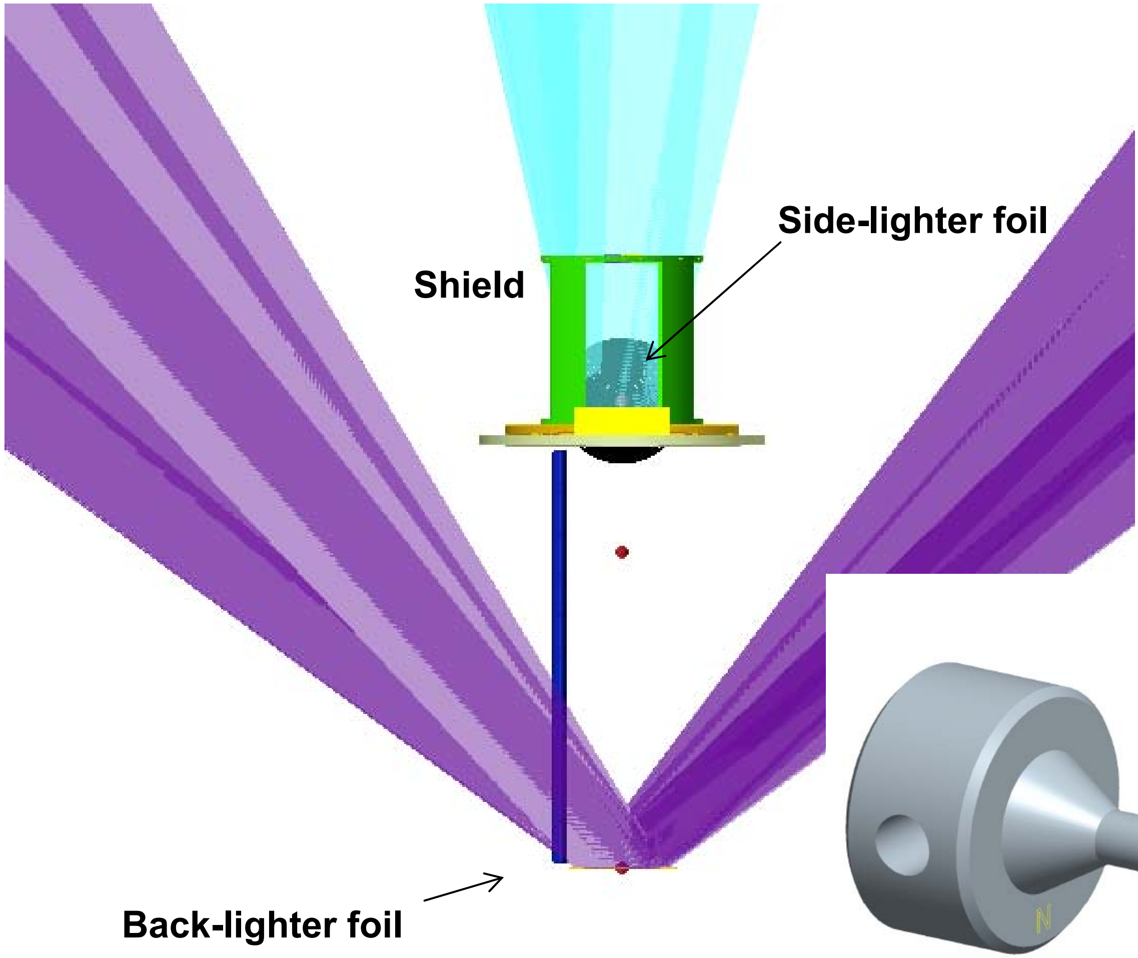
Face on
FOV

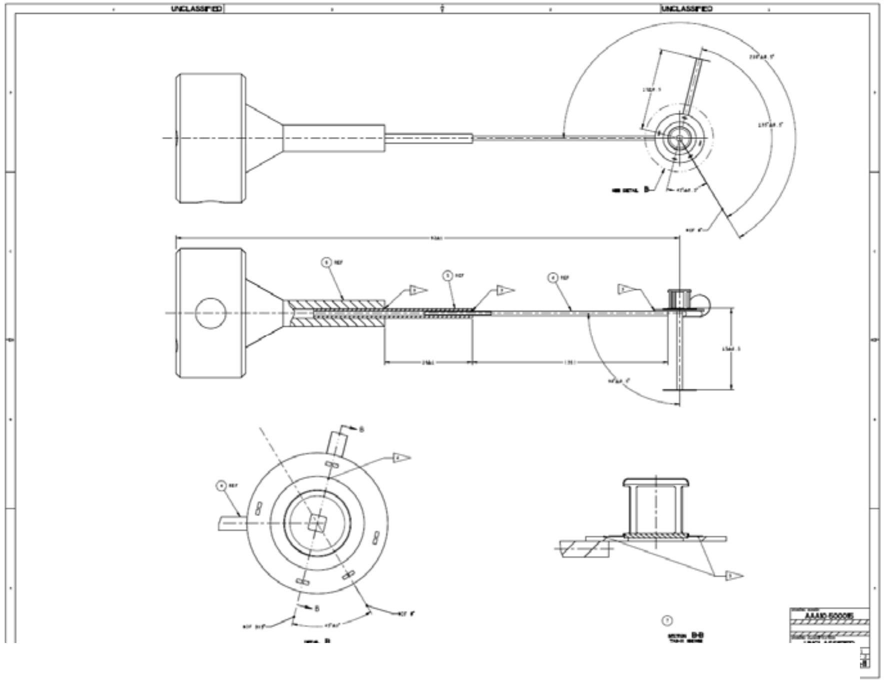
t = 14 ns

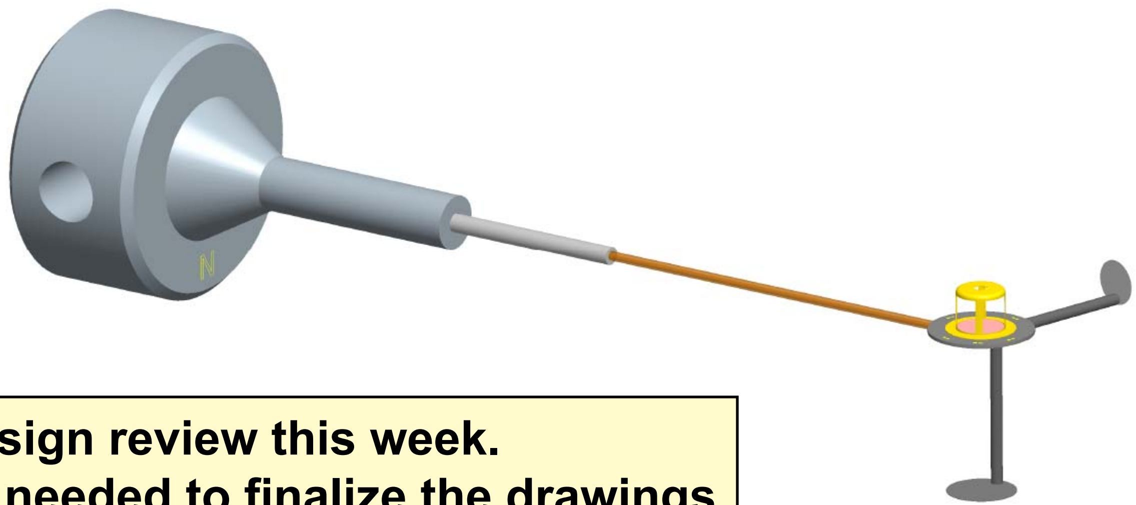


Whatever hydrocode predicts as a CLOS has to be demonstrated experimentally

Abl RT: Backlighter Performance Qualification shot (Tier 1 FY12) followed by Hohlraum PQ shot (Tier 2)







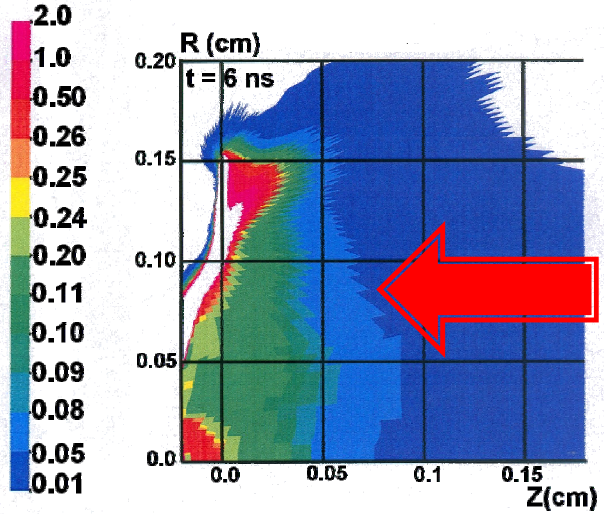
Final design review this week.
Target support is needed to finalize the drawings

Face-on Copper and Side-on Scandium backlighters: FCI2 calculations in the upper limit intensity case at 8.10^{14} W.cm^{-2}

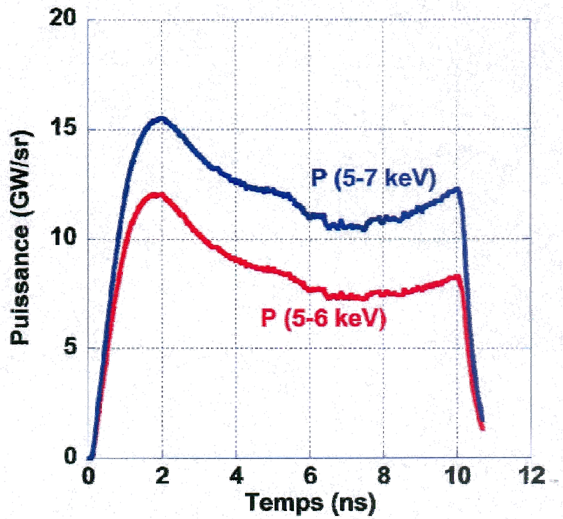
Vanadium Face-on BL

one-side irradiation
10 ns square pulse,
0.2 ns rise to Pm, Pm = 8 TW,
0.2 ns fall to 0
focal spot : 1186 µm × 1067 µm SG 4

C.E ~ 1 %



Density map

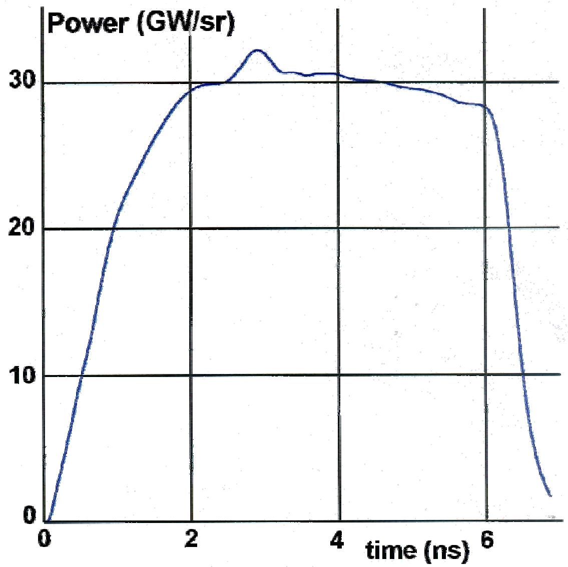


Power emitted in the foil normal axis (front side) and in the 5-7 keV range

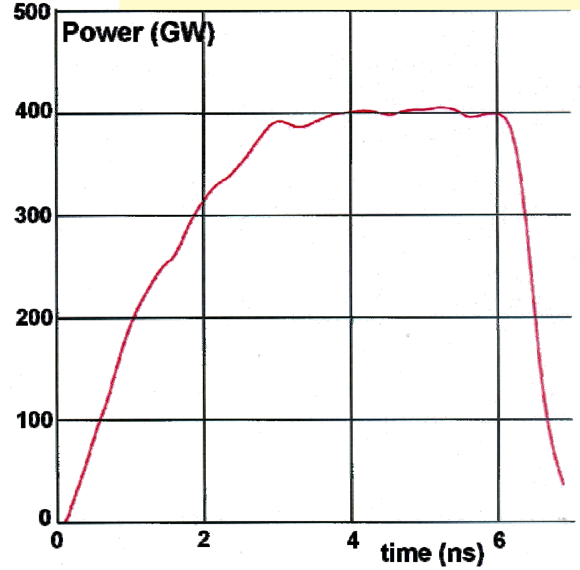
Scandium SL

two-side irradiation
on each side: a 6 ns square pulse,
0.2 ns rise to Pm, Pm = 8 TW,
0.2 ns fall to 0
focal spot : 1186 µm × 1067 µm SG 4

C.E ~ 2.5 %



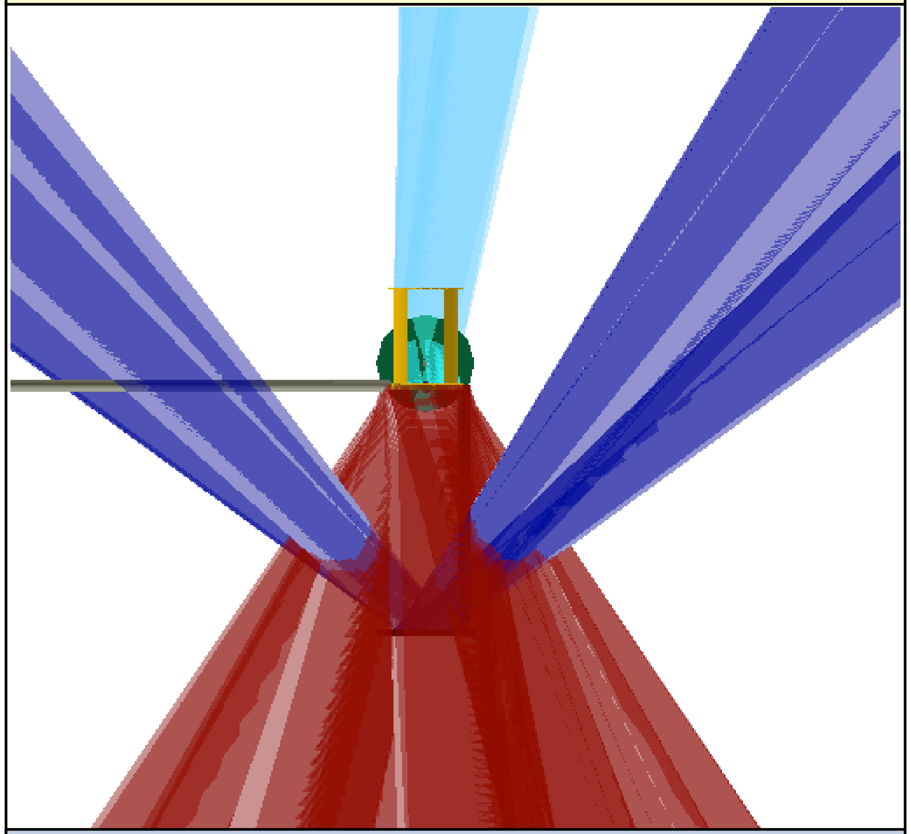
Power emitted in the foil normal axis and in the 4-5.5 keV range



Power emitted in 4π and in the 4-5.5 keV range

Ablative RT: Two platforms isolate ablative stabilization effects

Direct Drive Configuration

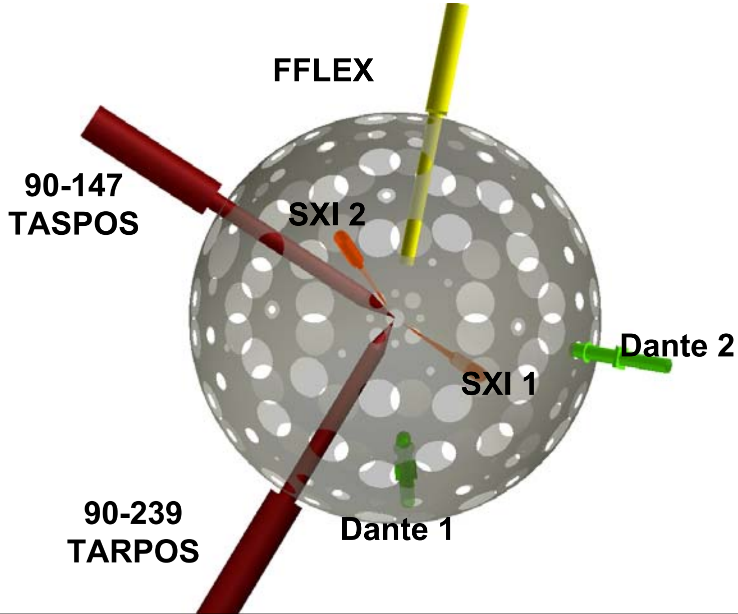


View from 90-315

Drive Pulse
20-ns square

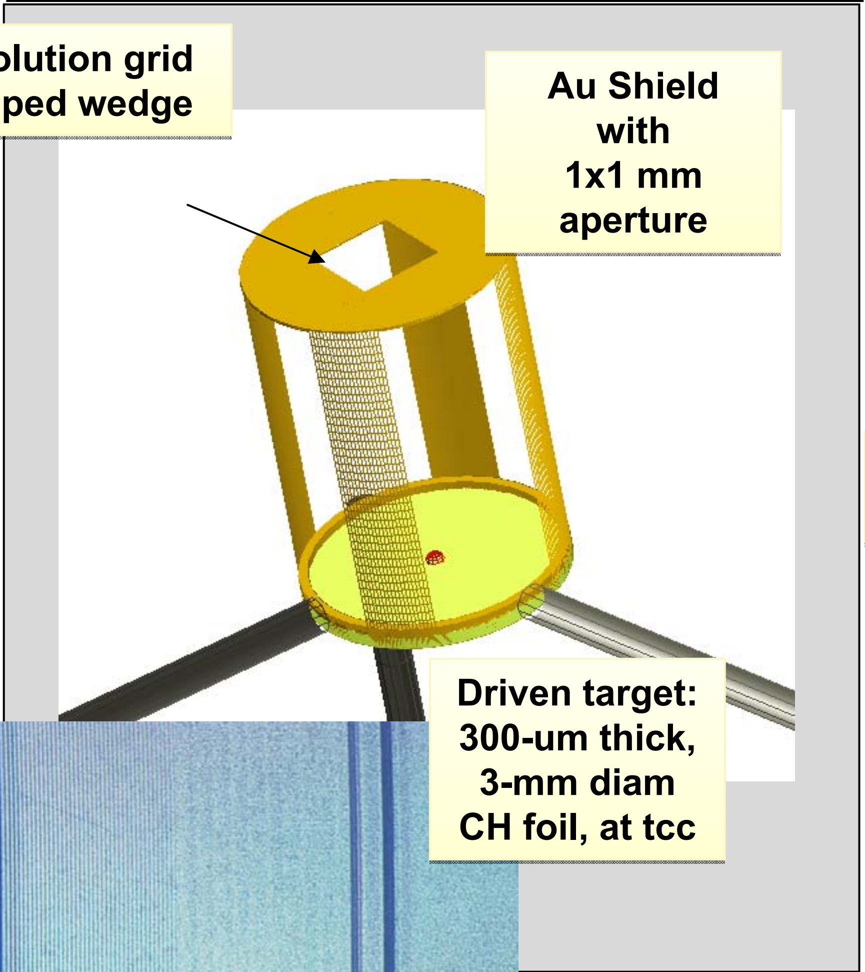
Total energy 184 kJ
Intensity 4.5e14 W/cm^2

Experimental layout,
Target chamber top view

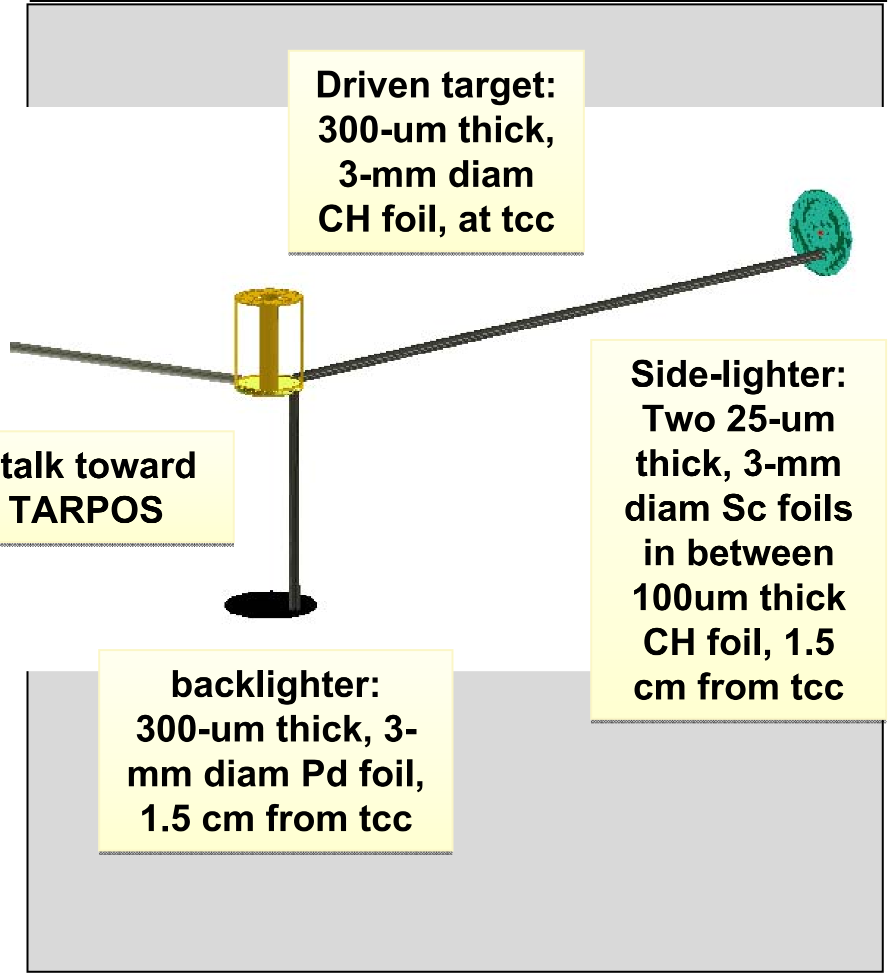


Diag	Location	Priority	Type	Calib
GXD-1	0-0	1	2	Pre-Shot
DISC-1	90,315	1	3	Pre-Shot
Dante 1	143,274	1	3	Pre-Shot
SXI, T/B	Fixed	3,2	3	Pre-Shot
FABS.NBI/FFLEX	Fixed	2-3	3	Pre-shot
GXD-2	90-78	2	2	Pre-Shot

Target #1: Type C



Alternative Target #1: Type C



Direct drive laser Requirements

Laser Parameter	Drive Value	Face-on BL Value	Sidelighter Value	Tolerance
1) Energy range per beam	5.75 kJ	5 kJ	5 kJ	5%
2) Pulse length	20 ns	10 ns	10 ns	±100 ps
3) Pulse shape	Square	10-ns square	10-ns square	Will further define variation on BL pulse
4) Power Balance	nominal	nominal	nominal	
5) SSD bandwidth	90 GHz	0-90 GHz	0-90 GHz	anything is acceptable
6) CPP design	Nominal CPPs	Nominal CPPs	Nominal CPPs	
7) Pulse delays	0.0 ns	6-10 ns	6-10 ns	±65 ps RMS
8) 2-color wavelength offset	No offset	No offset	No offset	
9) Beam pointing jitter	100 µm RMS	100 µm RMS	100 µm RMS	
10) Beam focus	Best focus	Best focus	Best focus	Spot size ± 0.05 mm
11) Post Pulse E upper limit				
12) Beam pointing location	x=0, y=0 z=0.1 cm	x=0, y=0,z=-1.5cm	x=-1.06 cm, y=1.06 cm z=0.0437 cm	± 100 µm RMS

NIF Laser Power

Drive Pulse
20-ns square
0.2875 TW per beam
8 quads
(Q15B, Q16B, Q21B, Q24B, Q31B, Q33B, Q42B, Q44B)

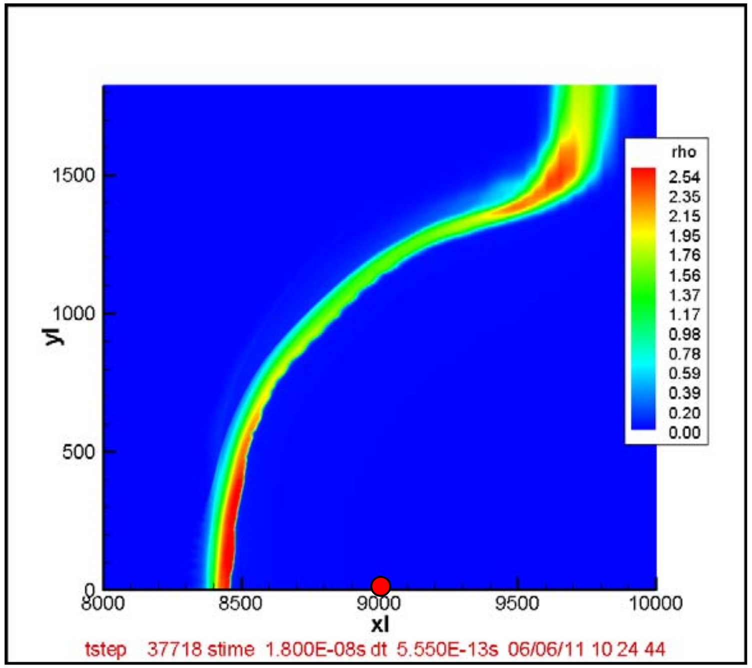
Total energy 184 kJ
Intensity 4.5e14 W/cm^2

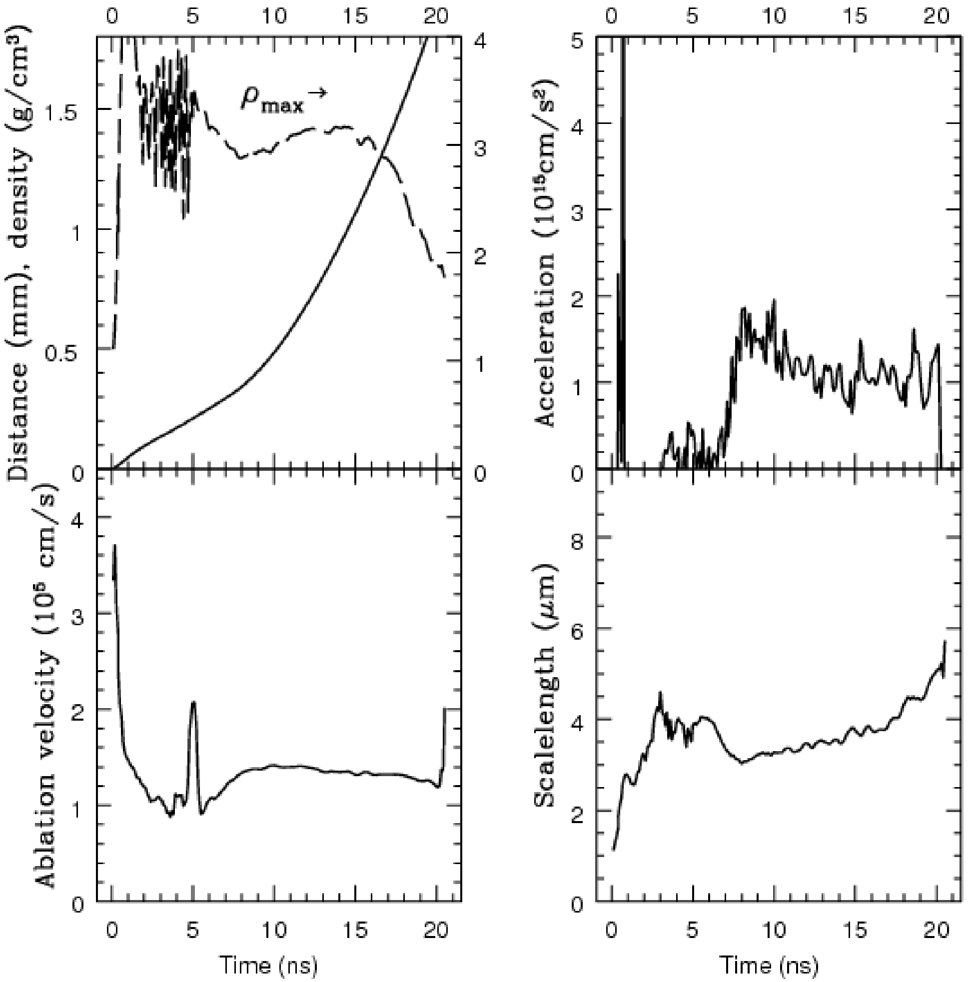
Backlighter Pulse
10-ns square
0.5 TW per beam
Up to 4 quads for backlighter
(Q11T, Q21T, Q31T, Q34T)
Total energy 80 kJ
Up to intensity 8e14 W/cm^2

4 quads for side-lighter
(Q46T, Q46B, Q23T, Q23B)
Total energy 40 kJ
Intensity 4.8e14 W/cm^2

300-µm thick CH foil is accelerated from 6.5 ns till ~20 ns by 20-ns square pulse

Ablative RT, direct-drive platform, beam offset = 1.0 mm



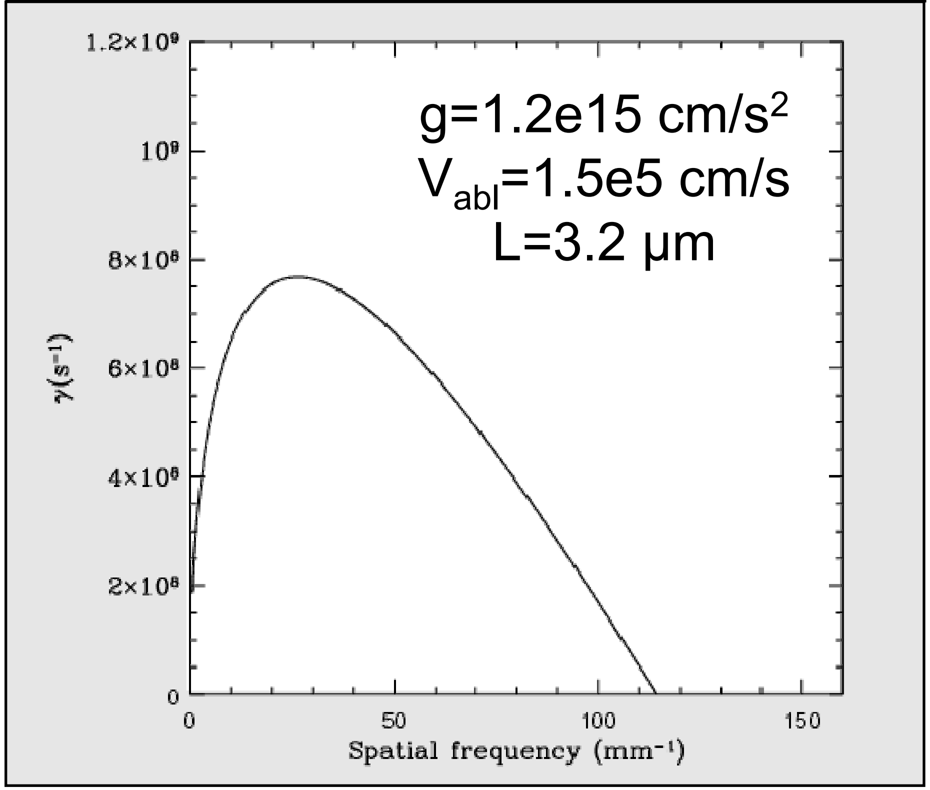


Offset 1.0 mm

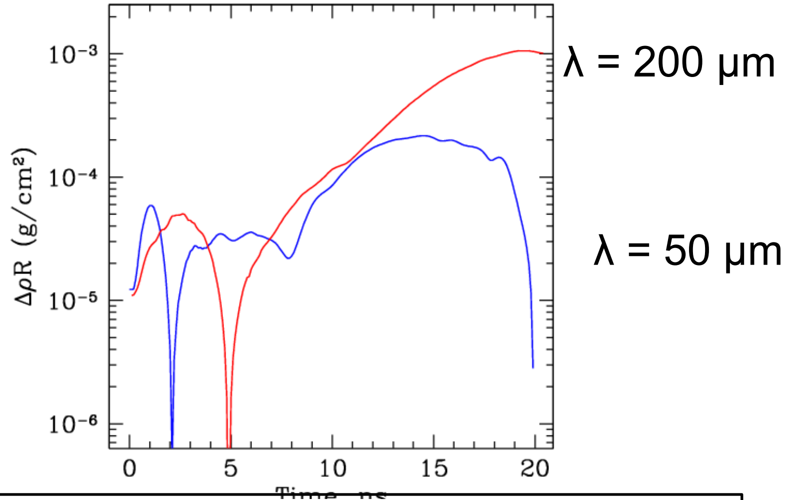
Beams are focused 1 mm behind initial foil position to minimize beam divergence effects and maintain the acceleration.

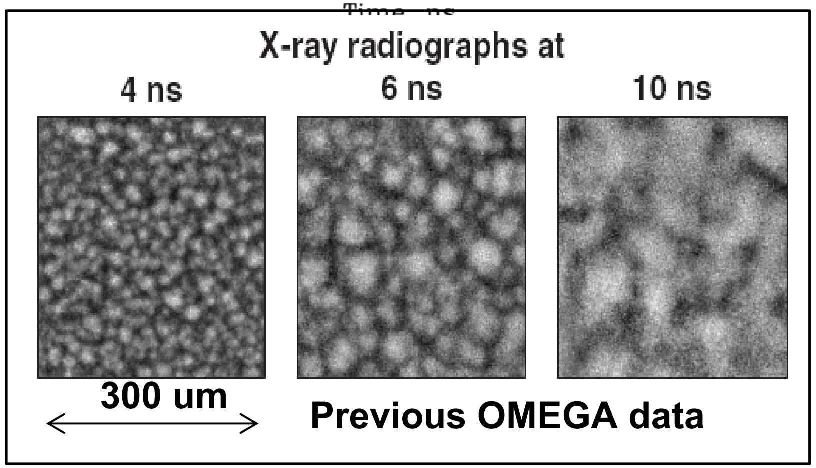
At least 3 more bubble generation than on OMEGA

Growth rate estimate in 300 µm CH at 13 ns



$$\gamma = \sqrt{\frac{kg}{1+kL}} - 1.5kV_{abl}$$

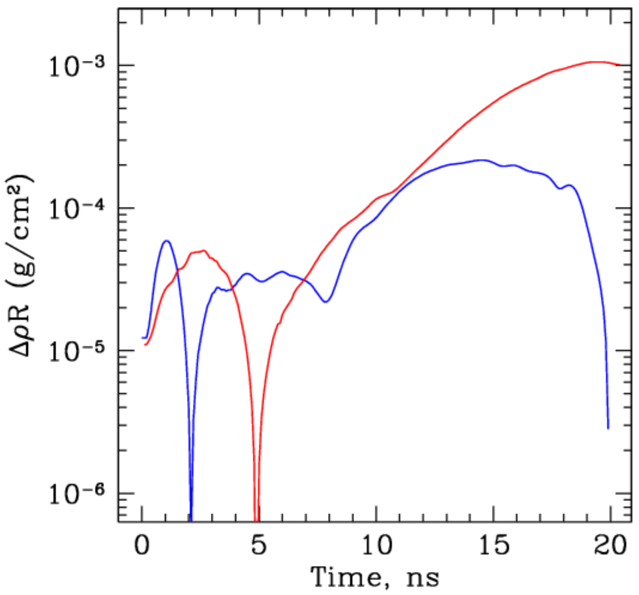




- **Growth rates are similar to OMEGA while target displacement is increased up to 10 times on NIF**
- **As bubble amplitude scale as gt^2 we expect 300 µm bubble which is 3 more generation of bubbles at 15 ns**
- **Shaping the drive will allow to tailor easily the initial conditions (cut-off, length scale)**

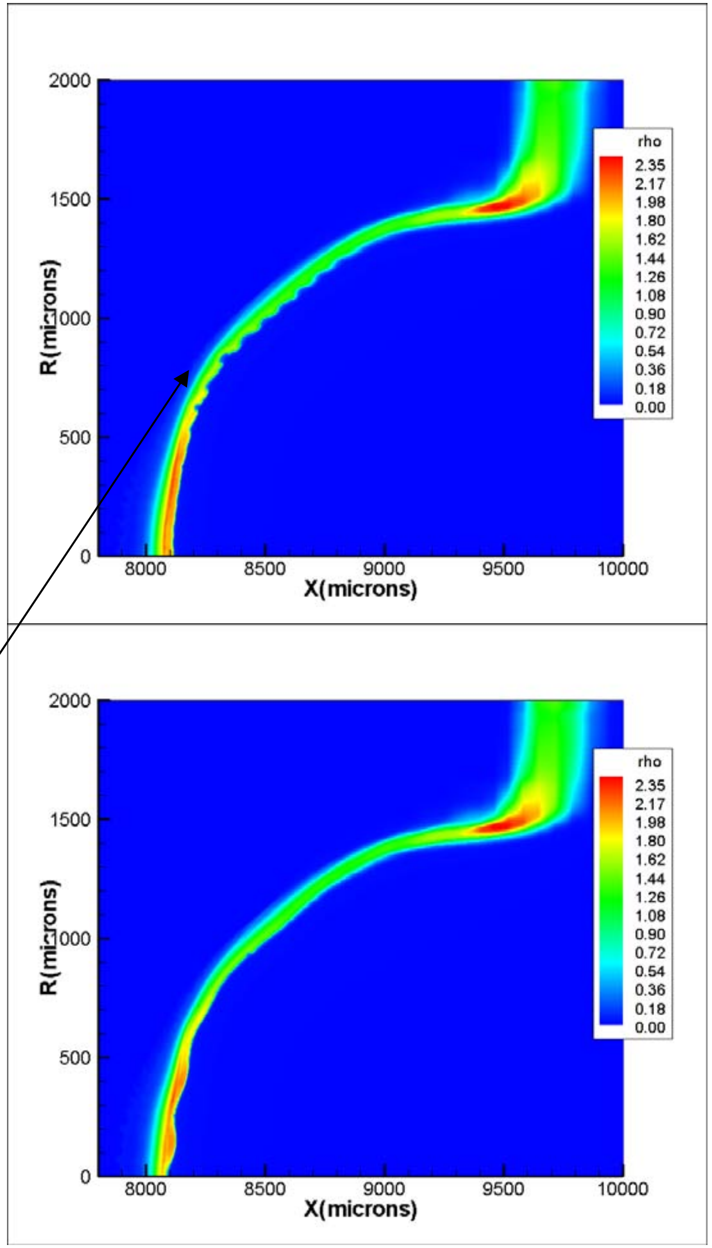
Lateral flow suppresses the perturbation growth at later time

Single mode simulations for λ=50 and 200µm



The growth of 50 µm perturbations is suppressed after ~15ns due to a lateral flow.

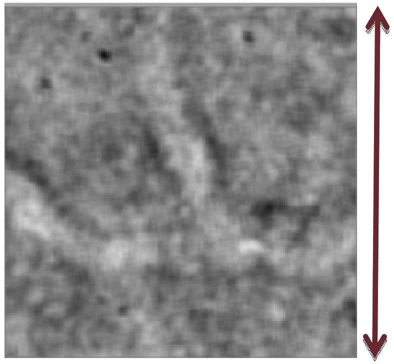
The 200um perturbations saturate at ~20ns, probably, due to the same lateral flow.



LBS OMEGA experiments allow us to study the Richtmyer-Meshkov seeding phase

Target thickness effects on modulation areal density

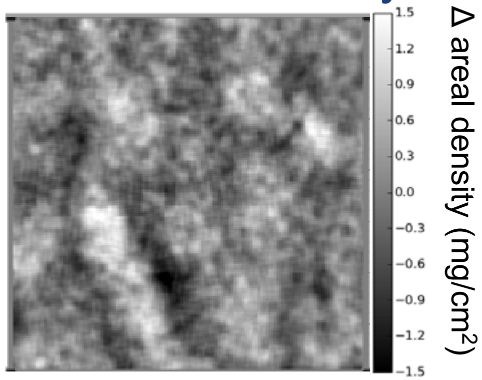
Sm Backlighter



350µm

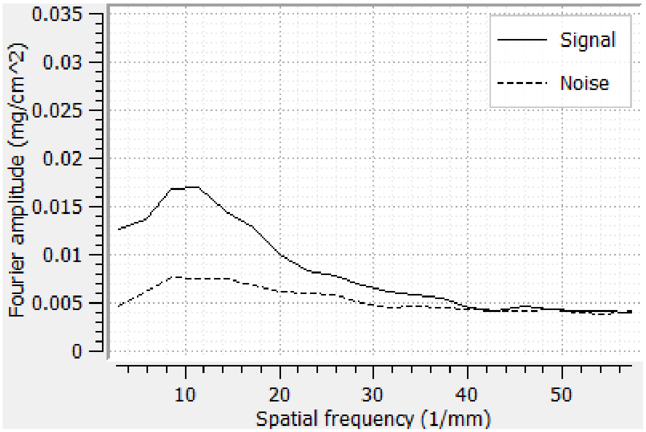
CH 30µm @t=0.9ns

Ta Backlighter

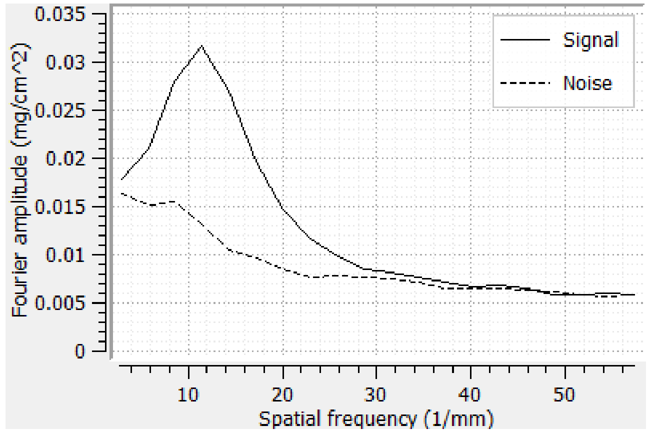


CH 50µm @t=1.7ns

Azimuthal average of Fourier spectrum



CH 30µm @t=0.9ns



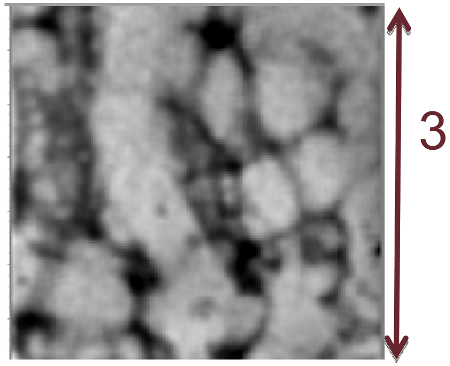
CH 50µm @t=1.7ns

Thicker targets allow the RM instability to grow to larger amplitudes at later times

Increased amplitude in RM causes an increase in RT growth at equivalent distance traveled.

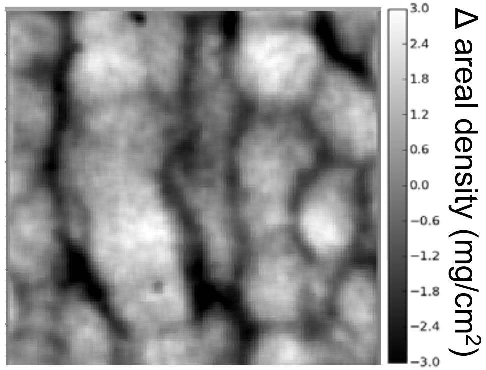
Modulation areal density compared at the same distance traveled

Sm Backlighter



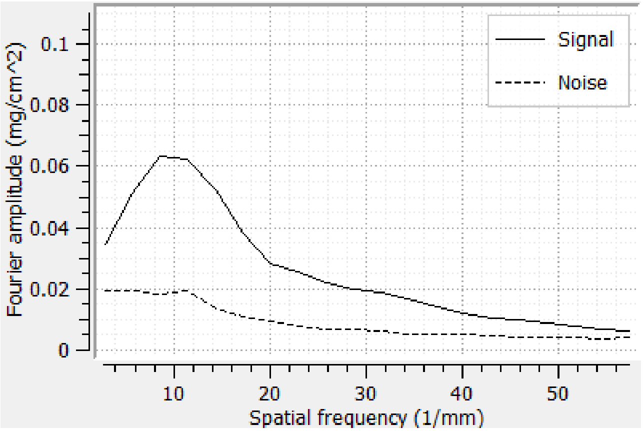
CH 30µm @t=2.4ns

Ta Backlighter

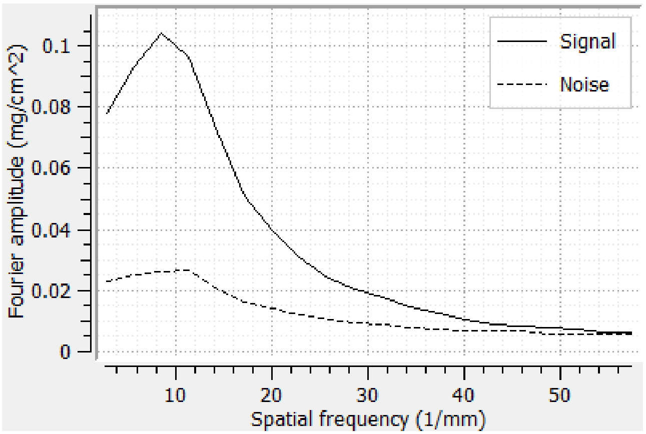


CH 50µm @t=3.2ns

Azimuthal average of Fourier spectrum



CH 30µm @t=2.4ns

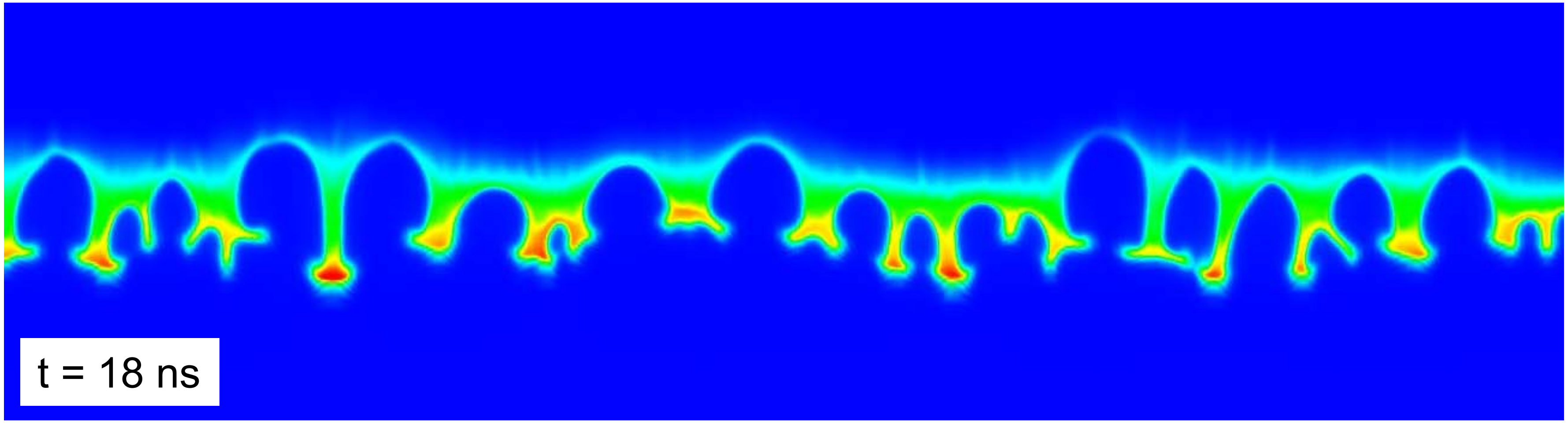


CH 50µm @t=3.2ns

More details : see B. Delorme, D. Martinez posters tomorrow

Ablative RT proposal objectives

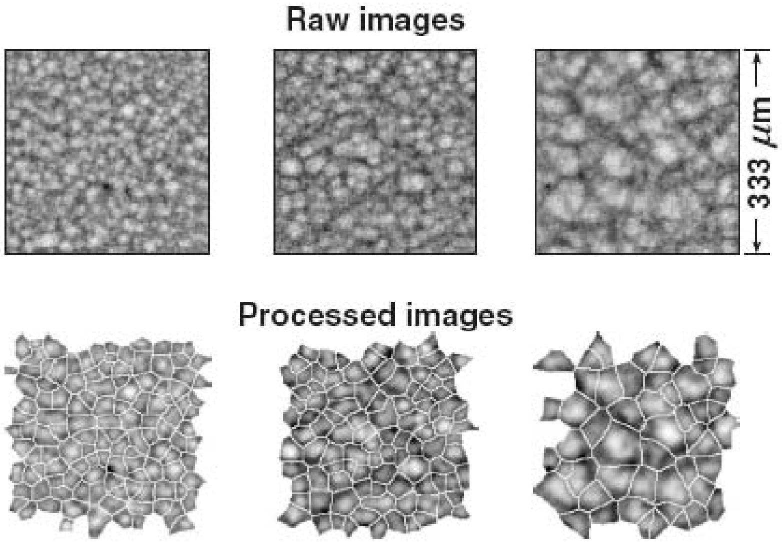
- The effect of ablation on RTI growth rate depends on the irradiating scheme: direct versus indirect drive.
- Multimode ablative Rayleigh Taylor Instability is not well understood, as well as turbulent front hydrodynamics.

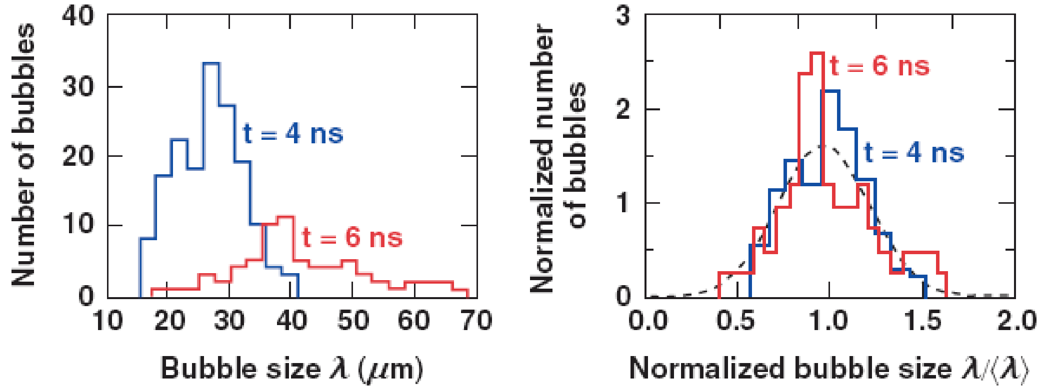


- NIF will accelerate targets over much larger distances (x6) and over longer time periods than ever achieved.
- In one shot, growth of RT modulations can be measured from the weakly nonlinear stage near nonlinear saturation levels to the highly nonlinear bubble-competition, bubble-merger regimes and perhaps into a turbulent-like regime.
- The result of the first DD planar RT shot on NIF will lead the way for academic IFE studies (Polar Direct Drive, Shock Ignition).
- We can perform these experiments right now, without any new diagnostics.
- We are developping a gas-filled hydrodynamics platform usefull for future experiments (Eagle nebula, ….)


NIF

Real-space bubble competition models describe Rayleigh–Taylor evolution more naturally

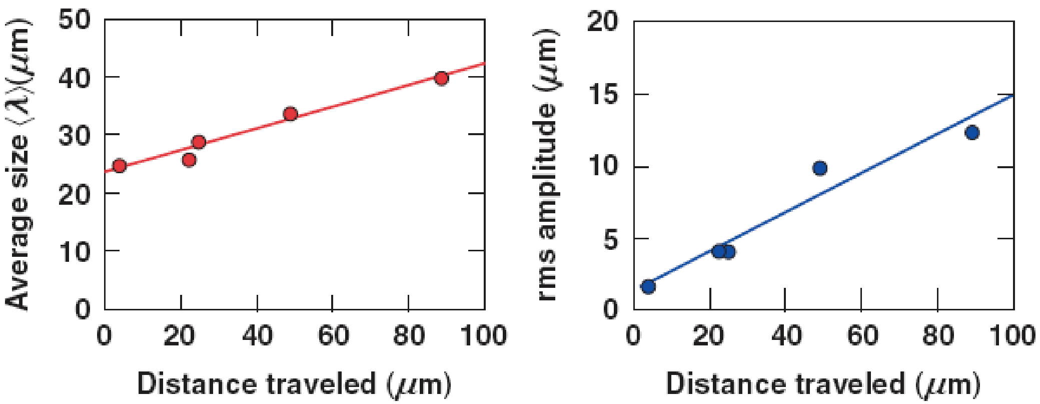




Measured distributions were fit with a normal distribution function.

$$f\left(\frac{\lambda}{\langle\lambda\rangle}\right) = \frac{1}{\sqrt{2\pi}\,C_\lambda} \exp\left[-\frac{\left(\frac{\lambda}{\langle\lambda\rangle}-1\right)^2}{\sqrt{2}\,C_\lambda^2}\right], \qquad C_\lambda = 0.24 \pm 0.01.$$

Real-Space Analysis

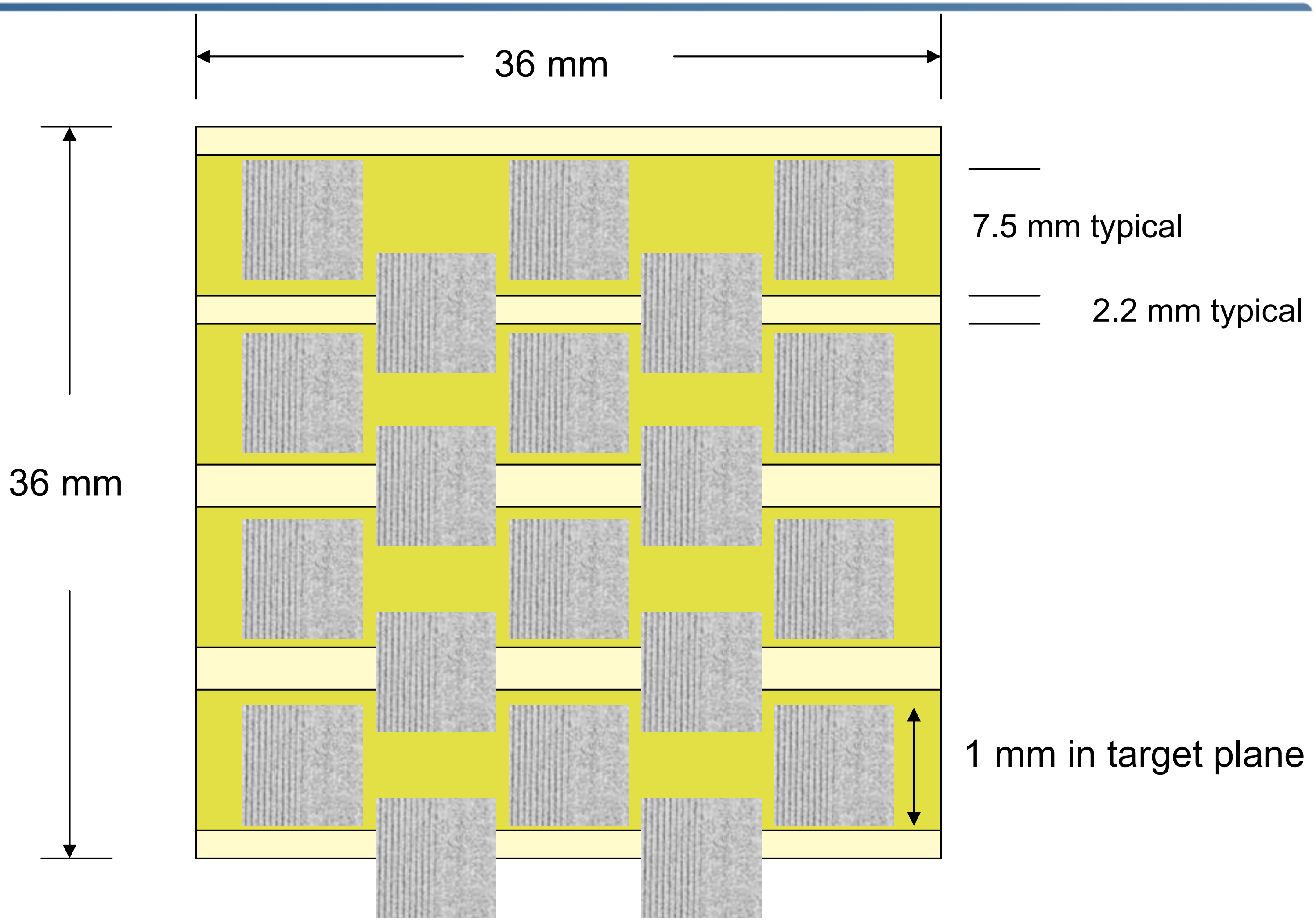


- The modulation σ_{rms} grows as $\alpha_\sigma g t^2$, with $\alpha_\sigma = 0.027 \pm 0.003$.

O. Sadot *et al.*, Phys. Rev. Lett. 95, 265001 (2005).

V. A. Smalyuk *et al.*, Phys. Plasmas. 13, 056312 (2006).

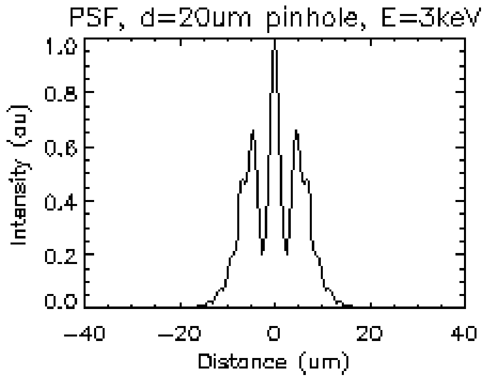
6.4x configuration for GXD-1 in DIM 0-0
Insensitive to 500 µm mispointing



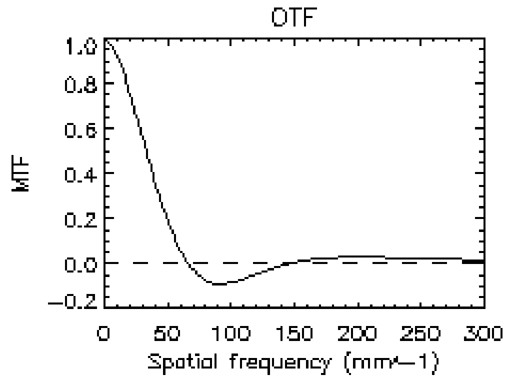
20-µm diam pinholes in 75-µm thick Ta substrate at 10 cm from tcc
Two standard 500 µm thick Ta collimators (diameter 50 µm)
GXD-1 at 74 cm from tcc
Max Filtration: Be – 500 µm total, or 100 µm polyimide

20-µm pinhole resolution is 20 µm or better at x-ray energies from 3 to 8 keV, resolution of the GXD is 50 µm.

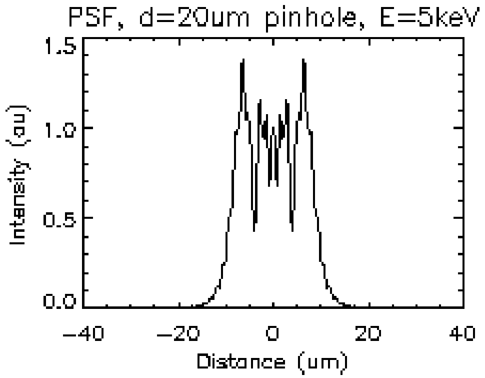
Point spread function at 3keV



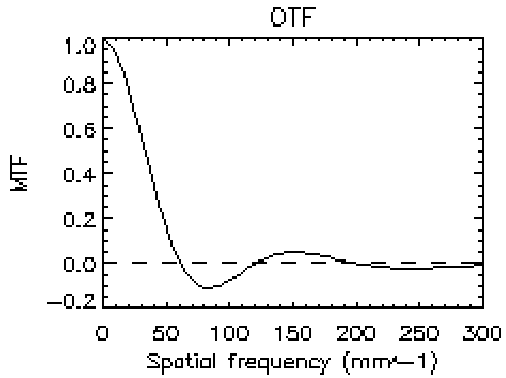
Modulation transfer function at 3keV



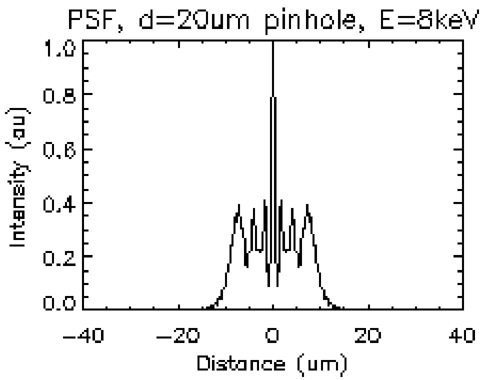
Point spread function at 5keV



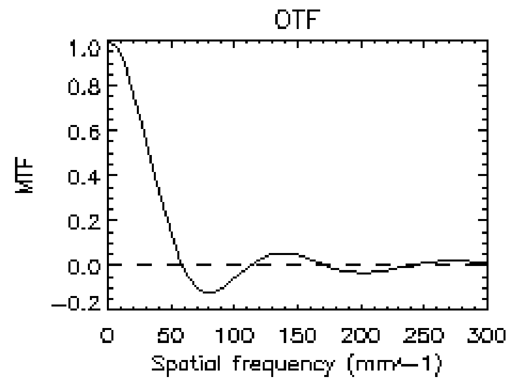
Modulation transfer function at 5keV



Point spread function at 8keV



Modulation transfer function at 8keV



Modulation transfer function of GXD